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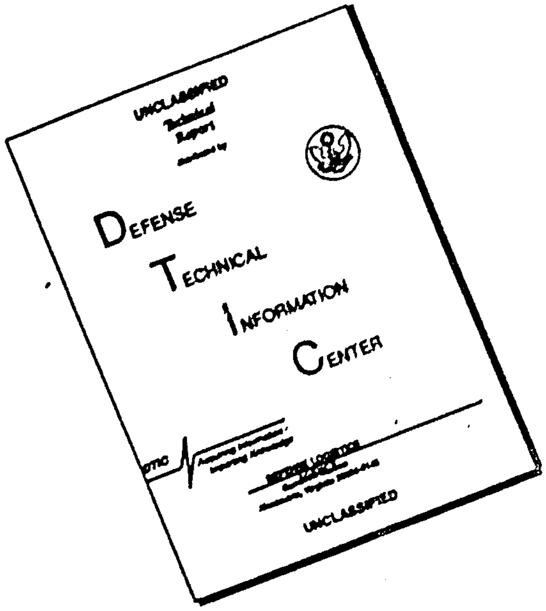

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Basic Research in the Navy

Volume II

Report to Secretary of the Navy by the Naval Research Advisory Committee

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Volume II

A REPORT TO THE

Secretary of the Navy

ON

Basic Research in the Navy

BY THE

Naval Research Advisory Committee

June 1, 1959

Report Prepared
by

Arthur D. Little, Inc.

UNDER OFFICE OF NAVAL RESEARCH CONTRACT NO. NONR-2516(00)

Introduction

Upon the recommendation of the Naval Research Advisory Committee, the Office of Naval Research initiated a contract with Arthur D. Little, Inc., February 1, 1958, to perform a study to determine a basis for decision as to the proper level of support of basic research by the Navy Department.

The report of this study is in two parts. Volume I is a brief monograph setting forth the principal findings. This is under separate cover. Volume II is a series of memoranda covering studies undertaken during the assignment, which led up to the principal findings. These are submitted herewith in the following appendixes:

A. Method of Approach

B. Mathematical Model

C. Manpower Studies

D. Chronology of Naval Technical Developments

E. References and Source Material

Appendix A

Method of Approach

The study was carried out by a team of people organized especially for the project under the over-all direction of a project leader. The team consisted of essentially three groups:

> Executives experienced in research and its administration and familiar with Government research policies and organization.
>
> Scientists experienced in basic research.
>
> Operations research personnel experienced in mathematical analysis and data handling.

Excellent liaison was established with the Navy through the Office of Naval Research and a special subcommittee of the Naval Research Advisory Committee.

the team was split into two major groups

Following the outline of a method of attack, the team was split into two major groups. One group was to collect information on basic research practices, policies, and personnel from Government, industry, and university sources; and analyze the data as to its application to the establishment of Navy policies. The second group was to attempt to develop quantitative methods of determining a proper level of Navy participation in basic research.

An extensive series of visits and interviews were arranged, and considerable correspondence with outstanding people in the field was undertaken. Among the groups or agencies contacted were:

Science Advisory Committee to the President, Office of Secretary of the Navy, Office of Naval Research, Office of Chief of Naval Operations, various Bureaus and Offices of the Navy Department dealing with research, a number of Navy laboratories, and the top technical people in nearly all the laboratories, Office of Assistant Secretary of Defense for Research and Engineering, National Science Foundation, Interdepartmental Committee on Scientific Research and Development, Central Intelligence Agency, Bureau of the Budget, and Armed Services Technical Information Agency.

Harvard, M.I.T. Lincoln Laboratory and Operations Evaluation Group, Columbia, Stanford, Buffalo, Rockefeller Foundation, Stanford Research Institute, Armour Research Foundation, Johns Hopkins University Applied Physics Laboratory and Operations Research Office, British Admiralty, Canadian Defense Board, Rand Corporation, and approximately fifty corporations considered leaders in basic research in industry and responsible for financing about 50 percent of all basic research expenditures by industry.

in every case complete co-operation was obtained

In every case complete cooperation was obtained, since the interest in the subject of this project is widespread. Ideas for attacking the assignment and data were solicited in all instances, and much information of value was obtained in this manner.

As approaches to the problem were decided upon and tentative conclusions drawn, discussions were held both with the Naval Research Advisory Committee and with outside experts who gave freely of their time. Drafts of the final reports were then prepared and reviewed in detail in the same manner.

Appendix B

A Model For The Discovery and Application of Knowledge

James C. Hetrick & George E. Kimball

It has been observed historically that the development of a field proceeds as a step function, with a "breakthrough" opening a new body of knowledge which is then explored and applied. Within the region of a single "step", the development follows the familiar S-shaped "growth" or "logistic" curve, as has been independently noted by several observers. An attempt is made here to derive a mathematical model which agrees with this observation and gives some insight into the necessary relationships among the several types of investigative effort.

To construct the model, let us initially postulate a logical universe defining a field of knowledge which can be expressed by a finite number of categorical statements. Within this universe, we characterize knowledge as being in three classes:

within this universe we characterize knowledge as being in three classes

A, the body of unknown fact,

B, the body of known, but unapplied fact, and

C, the body of applied fact.

We now assume that at a given level of effort, the rate of transition from A to B, or discovery, is proportional to A, and the rate of transition from B to C, or application, is proportional to B. This assumption leads to the familiar system

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

of chemical kinetics. Here, k_1 and k_2, having the dimensions of reciprocal time, express the fraction of the class converted per unit time and so measure the difficulty of discovery or application in the field. The formulation and solution of this system is as follows.

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

$$\frac{dA}{dt} = -k_1A$$

$$\frac{dB}{dt} = k_1A - k_2B \qquad \left.\begin{matrix} A = 1 \\ B = C = 0 \end{matrix}\right\} \text{at } t = 0$$

$$\frac{dC}{dt} = k_2B$$

For the intermediate, B

$$B = a_1e^{b_1t} + a_2e^{b_2t}$$

$$a_1 = -a_2 = k_1/(k_2 - k_1)$$

$$b_1 = -k_1 \qquad b_2 = -k_2$$

For the final stage, C

$$C = a_0 + a_3e^{b_3t} + a_4e^{b_4t}$$

$$a_0 = 1 \qquad a_3 = k_2/(k_1 - k_2) \qquad a_4 = k_1/(k_2 - k_1)$$

$$b_3 = -k_1 \qquad b_4 = -k_2$$

This solution gives a set of curves for A, B, and C as shown in Figure B-1, where the C curve corresponds to that empirically observed.

This simple formulation suffers from a defect in that it presents an unbelievable picture of the "B" state. Literally, it implies that the unit of knowledge once applied, cannot be re-applied in another context — an observation which is at variance with experience. We can explain this quite simply by saying that facts are not applied in units, but in combination. That is, the "k_2 process" yielding to application of knowledge, does not in general apply to a unit of knowledge, but to a conclusion drawn from a number of units of knowledge. Thus a fact may be applied many times, in different combinations with other facts. This however, leads to two difficulties in the simple kinetic model:

a fact may be applied many times, in different combination with other facts

1. The number of combinations available from a number of facts increases extremely rapidly as the number of facts increase, so that neither the B nor C curves will approach a limit, much less decrease.

2. In the event of assuming combinations of "A" state units being themselves "B" state units, the dimensionality of the equation for $\frac{dB}{dt}$ is erroneous.

To remove these objections, we postulate a model based on the following:

1. The results of the reasoning process can be expressed in sorites, or continued syllogisms.

2. The hypothetical and disjunctive syllogisms can be formally translated into categorical syllogisms.

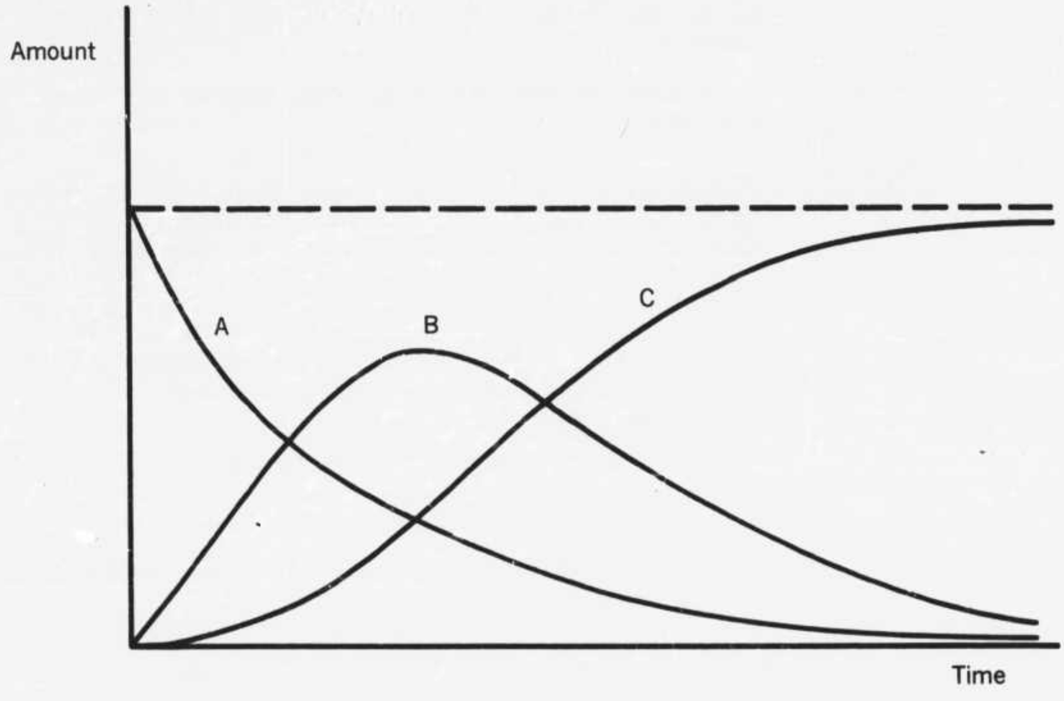


FIGURE B-1

3. All twenty-four valid categorical syllogisms may be reduced to Boolean algebraic formulations amenable to treatment by two theorems of the class-algebra, equivalent to the classical forms Barbara and Darii.

4. The two theorems are equivalent to the application of two relationships, a total inclusion relationship having the full properties of an algebraic inequality and a relationship of partial inclusion having only the property of transitivity over full inclusions, and under certain conditions.

a representation of the universe of knowledge

Under this postulation, the universe of knowledge may be represented as, for example

$$a_1 < a_2 < a_3 < \cdots\cdot < a_n < a_{n+1}$$

where the universe involves $(n + 1)$ classes, related by (n) categorical statements. It is evident, however, that only those statements which are adjacent in the ordered chain are combinatorially meaningful. Thus the statements $a_1 < a_2$ and $a_2 < a_3$ are combinatorially meaningful, and permit the combination (or "application") $a_1 < a_3$; while the statements $a_1 < a_2$ and $a_3 < a_4$ permit no valid conclusion, and hence cannot be applied. If this is so, then for a universe of n relationships, of which m are known, we have the following argument, for an application of such complexity as to require h facts.

The number of ways in which h may be drawn from n is

$$\frac{n(n-1)(n-2)\cdots(n-h+1)}{h!}$$

but the number of meaningful ways in which h facts may be drawn from a set of n ordered as shown is

$$(n - h + 1)$$

Thus the probability of a given group of h facts permitting the drawing of a valid conclusion, i.e., an application, is

$$\frac{h!}{n(n-1)(n-2)\cdots\cdot(n-h+2)}$$

But the number of ways in which h facts may be drawn from m is

$$\frac{m(m-1)(m-2)\cdots\cdot(m-h+1)}{h!}$$

Thus the expected number of possible applications of complexity h is the product of these two expressions

$$\left(\frac{m}{n}\right)\left(\frac{m-1}{n-1}\right)\left(\frac{m-2}{n-2}\right)\cdots\left(\frac{m-h+2}{n-h+2}\right)(m-h+1)$$

The total number of applications possible is

$$\sum_{h=2}^{h}\left(\frac{m}{n}\right)\left(\frac{m-1}{n-1}\right)\cdots\left(\frac{m-h+2}{n-h+2}\right)(m-h+1)$$

If now we assume that h is small compared to m and n, i.e., any application draws on only a fraction of known fact this becomes

$$m\sum_{j=1}^{h-1}\left(\frac{m}{n}\right)^j$$

If this is taken as an infinite series (which will actually violate the approximation introduced above) the expression reduces to

$$\frac{m\left(\frac{m}{n}\right)}{1-\left(\frac{m}{n}\right)} = \frac{m^2}{n-m}$$

In terms of the postulated two-stage process,

$$m = A_o - A,\ n = A_o \text{ and}$$

$$B + C = \frac{m^2}{n-m} = \frac{(A_o - A)^2}{A}$$

so that the system becomes

$$\frac{dA}{dt} = -k_1 A$$

$$\frac{dC}{dt} = k_2 B$$

$$B + C = \frac{(A_o - A)^2}{A}$$

to which the solution is

$$A = A_o e^{-k_1 t}$$

$$B = k_1 A_o\left[\frac{e^{k_1 t}}{k_1 + k_2} + \frac{e^{-k_1 t}}{k_1 - k_2} + \frac{2k_1 e^{-k_2 t}}{k_2^2 - k_1^2}\right]$$

$$C = k_1 k_2 A_o\left[\frac{e^{k_1 t}}{k_1(k_1 + k_2)} - \frac{e^{-k_1 t}}{k_1(k_1 - k_2)} + \frac{2k_1 e^{-k_2 t}}{k_2(k_1^2 - k_2^2)}\right]$$

In these equations, the term $e^{k_1 t}$ increases without limit, because of the assumption an infinite series implies $j \to \infty$. If an appropriate limit is imposed on the term to satisfy the assumptions that $h << m < n << \infty$, the expression is seen to be of the form required in the kinetic model.

The development can, alternatively, be carried through use of the proper conversion of the expression

$$m\sum_{j=1}^{h-1}\left(\frac{m}{n}\right)^j$$

as a geometric series of $(h - 2)$ terms. This is equal to

$$m \cdot \frac{m}{n} \cdot \left[1 - \left(\frac{m}{n}\right)^{h-1}\right] \Big/ \left[1 - \left(\frac{m}{n}\right)\right] = \frac{m^2}{n-m}\left[1 - \left(\frac{m}{n}\right)^{h-1}\right]$$

where again $n = A_o$; $m = A_o - A$ and hence

$$B + C = \frac{m^2}{n - m}\left[1 - \frac{m^{k-1}}{n}\right]$$

$$= \frac{(A_o - A)^2}{A}\left[1 - \left(\frac{A_o - A}{A_o}\right)^{k-1}\right]$$

The resulting series of equations are best solved numerically, rather than analytically. When this is done, again curves of the proper shape are obtained.

more complicated cases give similar, but more elaborate equations

More complicated cases, such as those in which branching is introduced into the chain of relationships between classes, give similar but more elaborate equations which again on numerical solution give curves of the proper form. Accordingly, it is assumed that the basic form of the C curve as being a constant minus two exponentials.

Let us now consider such an expression, containing two exponentials and possibly a constant. Thus in the first formulation for B we have

$$B = a_1e^{b_1t} + a_2e^{b_2t}$$

Now consider three successive points taken for equally spaced values of t

$$B_i = a_1e^{b_1t_i} + a_2e^{b_2t_i} \tag{1}$$

$$B_{i+1} = a_1e^{b_1t_i}e^{b_1\Delta t} + a_2e^{b_2t_i}e^{b_2\Delta t} \tag{2}$$

$$B_{i+2} = a_1e^{b_1t_i}e^{b_12\Delta t} + a_2e^{b_2t_i}e^{b_22\Delta t} \tag{3}$$

If now we multiply (1) by $e^{b_1\Delta t}$ and subtract from (2), and multiply (2) by $e^{b_1\Delta t}$ and subtract from (3), we have

$$B_{i+1} - e^{b_1\Delta t}B_i = a_2e^{b_2t_i}(e^{b_2\Delta t} - e^{b_1\Delta t}) \tag{4}$$

$$B_{i+2} - e^{b_1\Delta t}B_{i+1} = a_2e^{b_2t_i}(e^{b_22\Delta t} - e^{(b_1+b_2)\Delta t}) \tag{5}$$

Now, multiplying (4) by $e^{b_2\Delta t}$ and subtracting from (5), there results

$$B_{i+2} - (e^{b_1\Delta t} + e^{b_2\Delta t})B_{i+1} + e^{(b_1+b_2)\Delta t}B_i = 0 \tag{6}$$

From which

$$\frac{B_{i+2}}{B_i} = \left(e^{b_1\Delta t} + e^{b_2\Delta t}\right)\frac{B_{i+1}}{B_i} - e^{(b_1+b_2)\Delta t} \tag{7}$$

Thus if the indicated ratios are plotted, the points should fall on a straight line of slope m and intercept b such that the roots of the quadratic

$$x^2 - mx + b = 0$$

are $e^{b_1\Delta t}$ and $e^{b_2\Delta t}$. A similar expression results if C alone is known as a function of t, except that the successive increments ΔC at equal Δt are used. To illustrate this, synthetic data for the intermediate, B, in a system with $k_1 = 0.10$ and $k_2 = 0.05$ are plotted in Figure B-2. The accompanying curve, Figure B-3, for $\Delta t = 5$ is the straight line

$$\frac{B_{i+2}}{B_i} = 1.385\,\frac{B_{i+1}}{B_i} - 0.4724$$

which gives values $k_1 = 0.0988$ and $k_2 = .0508$. The following Figure B-4 gives C as a function of t for the same system, and in Figure B-5 the ΔC ratios plot to the same straight line.

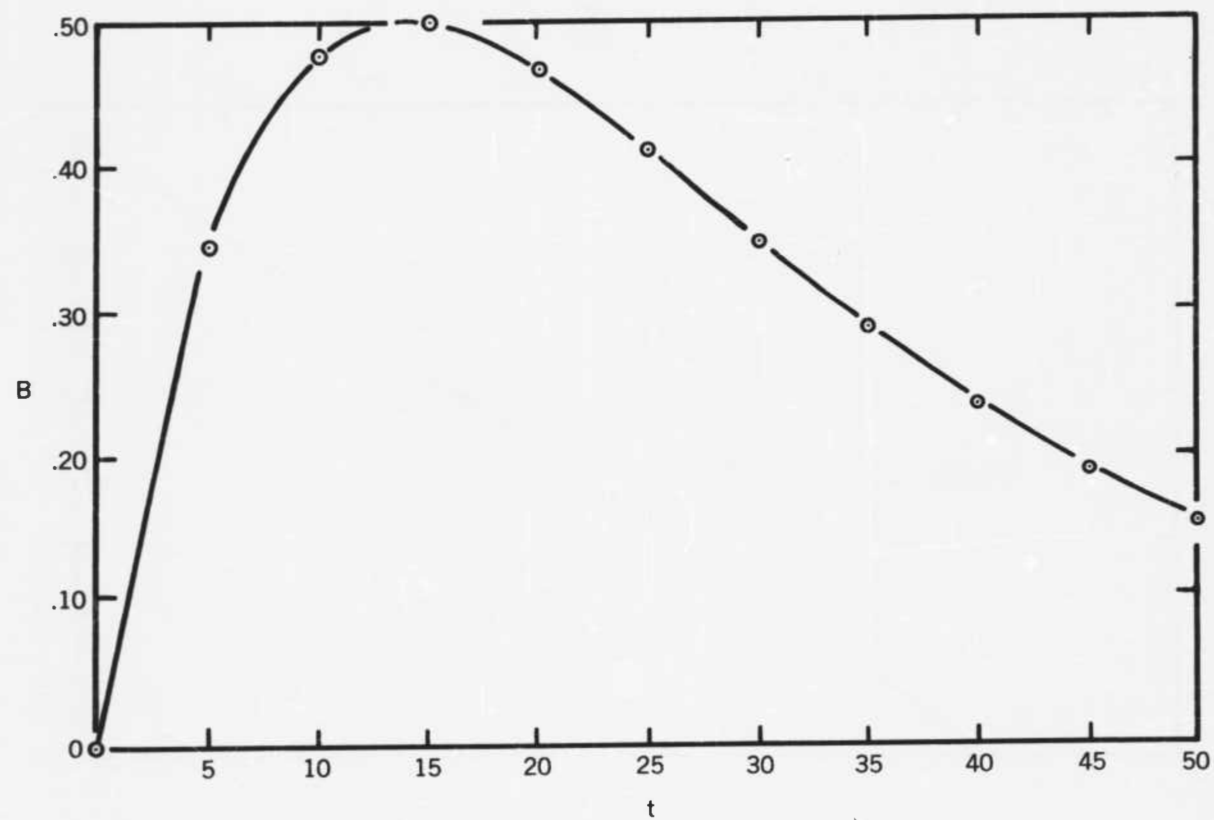
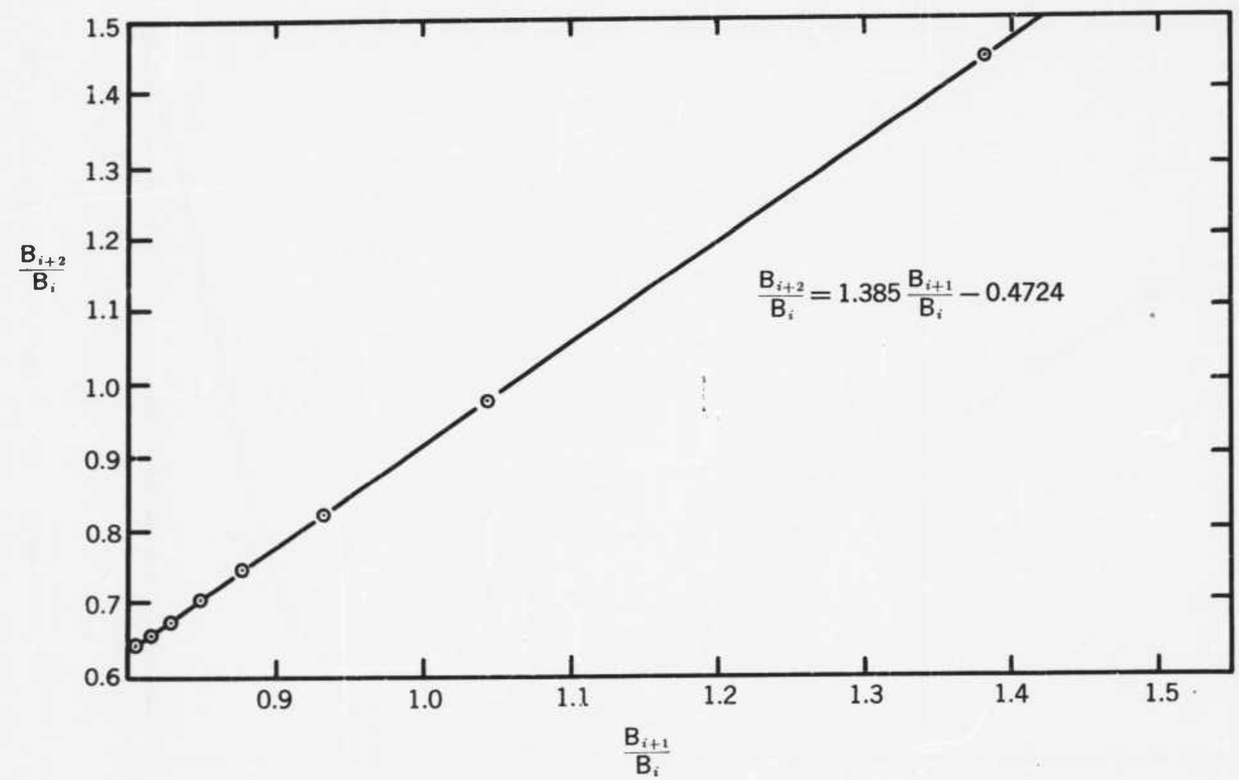


FIGURE B-2



1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
$\frac{B_{i+2}}{B_i}$
$\frac{B_{i+2}}{B_i} = 1.385 \frac{B_{i+1}}{B_i} - 0.4724$
0.9
1.0
1.1
1.2
1.3
1.4
1.5
$\frac{B_{i+1}}{B_i}$

FIGURE B-3

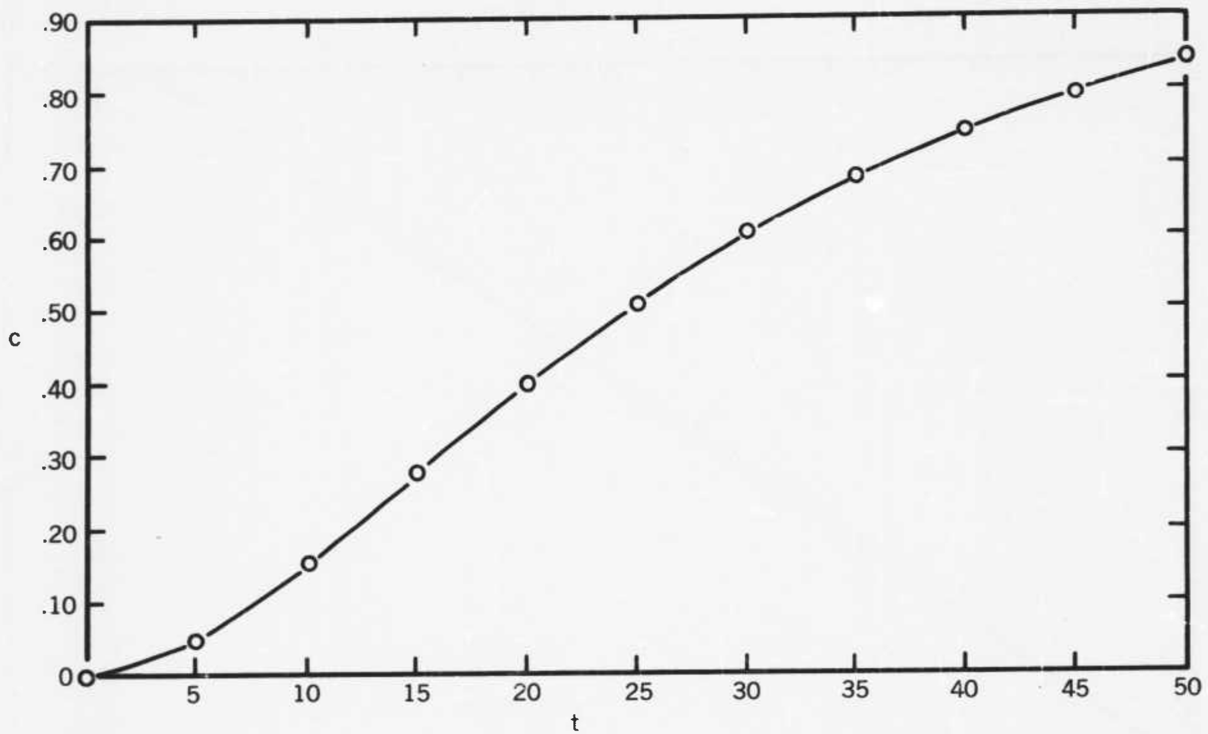


FIGURE B-4

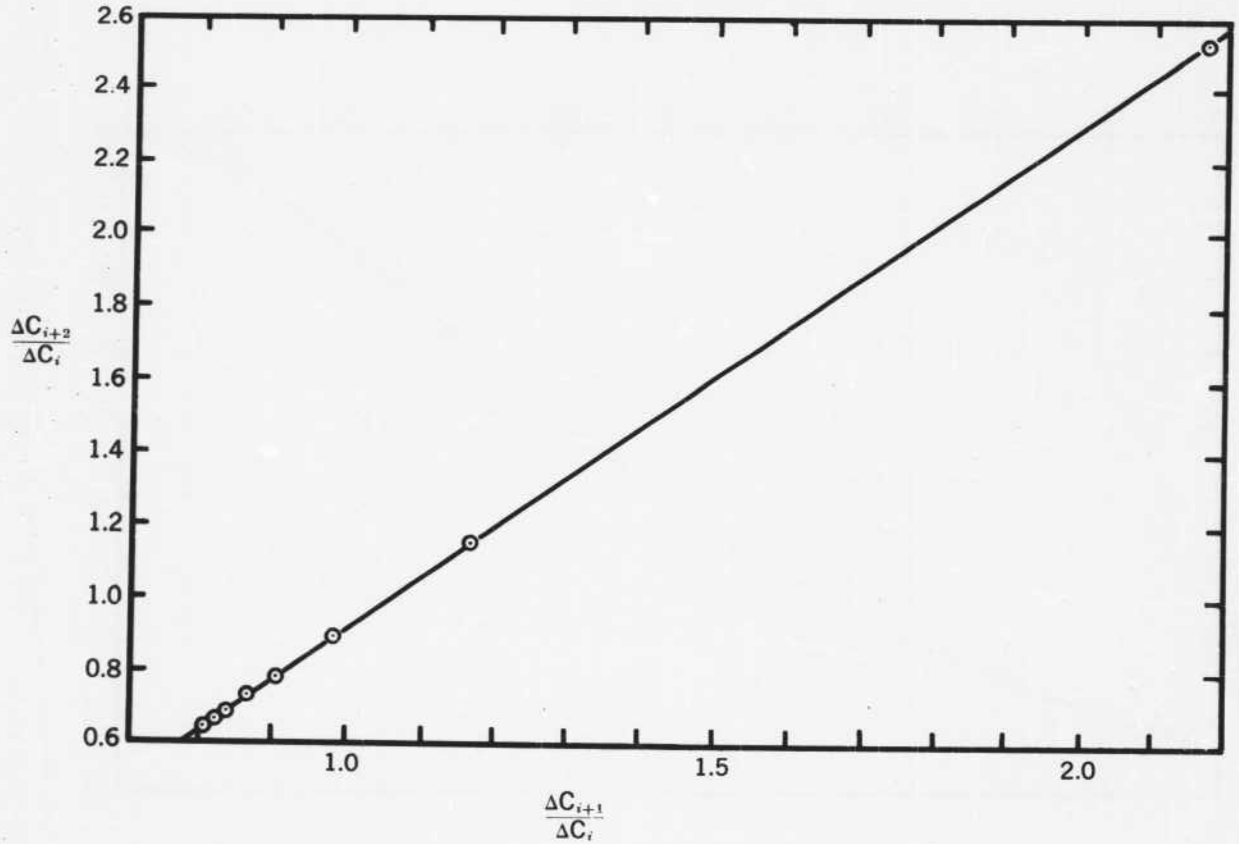

2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
$\frac{\Delta C_{i+2}}{\Delta C_i}$
1.0
1.5
2.0
$\frac{\Delta C_{i+1}}{\Delta C_i}$

FIGURE B-5

historical data on six industrial research projects

The cooperation of a very large industrial research organization was secured and historical data on six of their research projects given us. This data is given, and the terms defined, in Table B-I. The derived straight lines, found by the method described, are presented in Figures B-6 to B-11 following. It will be noted that in spite of the scatter in the right hand portion of the curves (which are generated by the left hand portion of the growth curves, i.e., the early stages of the work where small errors are large relative to the true value) a reasonably good fit to straight lines is observed. Thus it may be concluded that the rate at which the work was carried on, representing an experienced research management's judgment as to the optimum allocation of its available effort, can be consistent with the model proposed. For purposes of comparison, all of the fitted straight lines are plotted together in Figure B-12, and it will be observed that the lines all lie within a very narrow range. The k values cannot be calculated from these data, the absolute time scale being unknown, but the coincidence of the straight lines would indicate that the ratio k_1/k_2 is close to being constant. This might mean a consistent research managerial policy, or it might indicate that the ratio is in fact characteristic of the field of science wherein the work lies.

Up to this point it has been assumed that k_1 and k_2 are constants. In this case, as we have just shown, their values can be evaluated. In general, however, the amounts of effort put into the two stages may vary with time. Under such circumstances it is reasonable to assume that the rate of each step is proportional to the effort (E_1, E_2) put into that stage. If this is the case, the rate equations are modified to become

$$dA/dt = -k_1E_1A \qquad (8a)$$

$$dB/dt = k_1E_1A - k_2E_2B \qquad (8b)$$

$$dC/dt = k_2E_2B \qquad (8c)$$

where k_1 and k_2 are proportionality constants. The larger the magnitude of these constants, the greater the ease of the corresponding processes. Note that E_1 and E_2 are both generally functions of time.

One integral of these equations is found immediately by adding the three equations. It is the conservation law

$$A + B + C = A_o \qquad (9)$$

The complete solution of these equations is most conveniently expressed in terms of the quantities F_1 and F_2 defined by

$$F_1 = \int_o^t E_1 dt \qquad (10a)$$

$$F_2 = \int_o^t E_2 dt \qquad (10b)$$

Physically, F_1 is the total effort put into basic research up to time t, and

TABLE B-1

The Development Effort* Utilized on Various Projects, Plotted as a Percent of the total Effort Utilized at Given Percentages of Calendar Time Required to Complete the Project.

Percent of Calendar Time	Percent of Total Development Effort Utilized					
	I	II	III	IV	V	VI
5.0	0.6	0.3	0.8	0.6	0.5	0.6
10.0	1.5	0.7	2.0	1.8	1.0	1.4
15.0	2.3	1.2	4.1	3.1	1.8	2.3
20.0	3.5	2.2	7.3	4.9	2.8	3.5
25.0	5.6	3.9	11.0	7.8	4.1	5.4
30.0	8.9	6.0	15.7	12.9	6.5	8.7
35.0	12.5	8.1	20.9	19.3	10.1	12.6
40.0	15.5	11.3	26.9	26.7	14.6	17.3
45.0	18.5	15.9	34.2	34.4	20.3	22.8
50.0	22.3	22.6	42.1	42.1	25.9	29.6
55.0	27.7	31.4	48.9	50.4	33.3	37.9
60.0	34.8	41.7	56.0	58.4	41.8	45.7
65.0	43.1	51.9	63.3	65.9	49.6	53.7
70.0	52.1	61.0	70.5	73.0	57.3	61.6
75.0	61.4	69.5	77.6	79.9	65.5	69.0
80.0	70.4	77.2	84.7	86.9	73.4	76.1
85.0	78.9	84.1	91.9	92.5	81.0	83.3
90.0	86.8	89.8	95.7	95.3	88.3	89.6
95.0	94.2	94.9	98.4	98.2	94.8	94.9
100.0	100.0	100.0	100.0	100.0	100.0	100.0

*** Development Effort is defined as all engineering effort, technical assistance and shop time arising within the Product Development Laboratory to the point where the project was 100% released.**

N. B. Projects I, II, V and VI are generically similar projects resulting in major products. Project III was run as an adjunct to Project II. It resulted in a minor product. Project IV resulted in a major product that was never marketed.

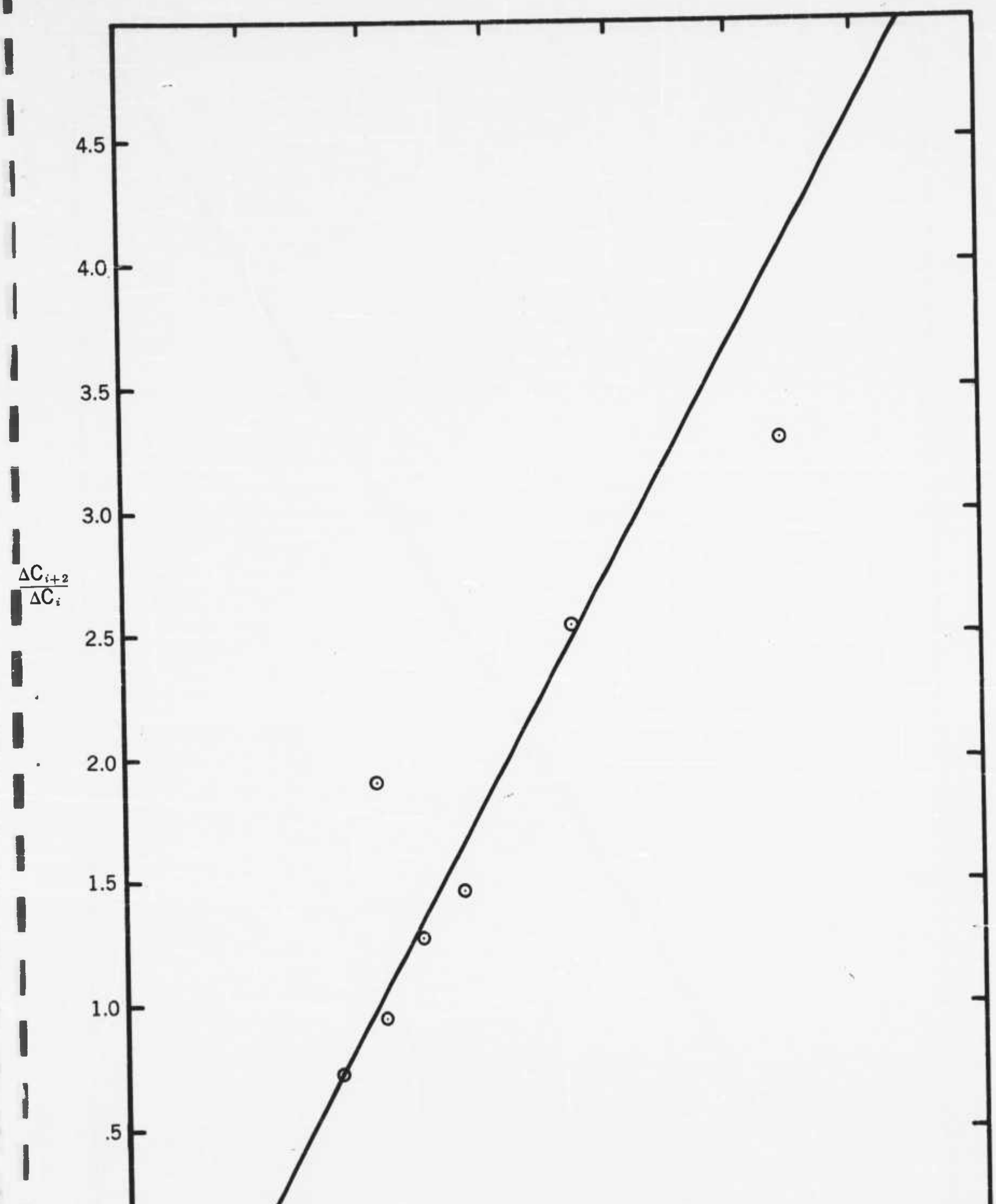


FIGURE B-6
PROJECT I

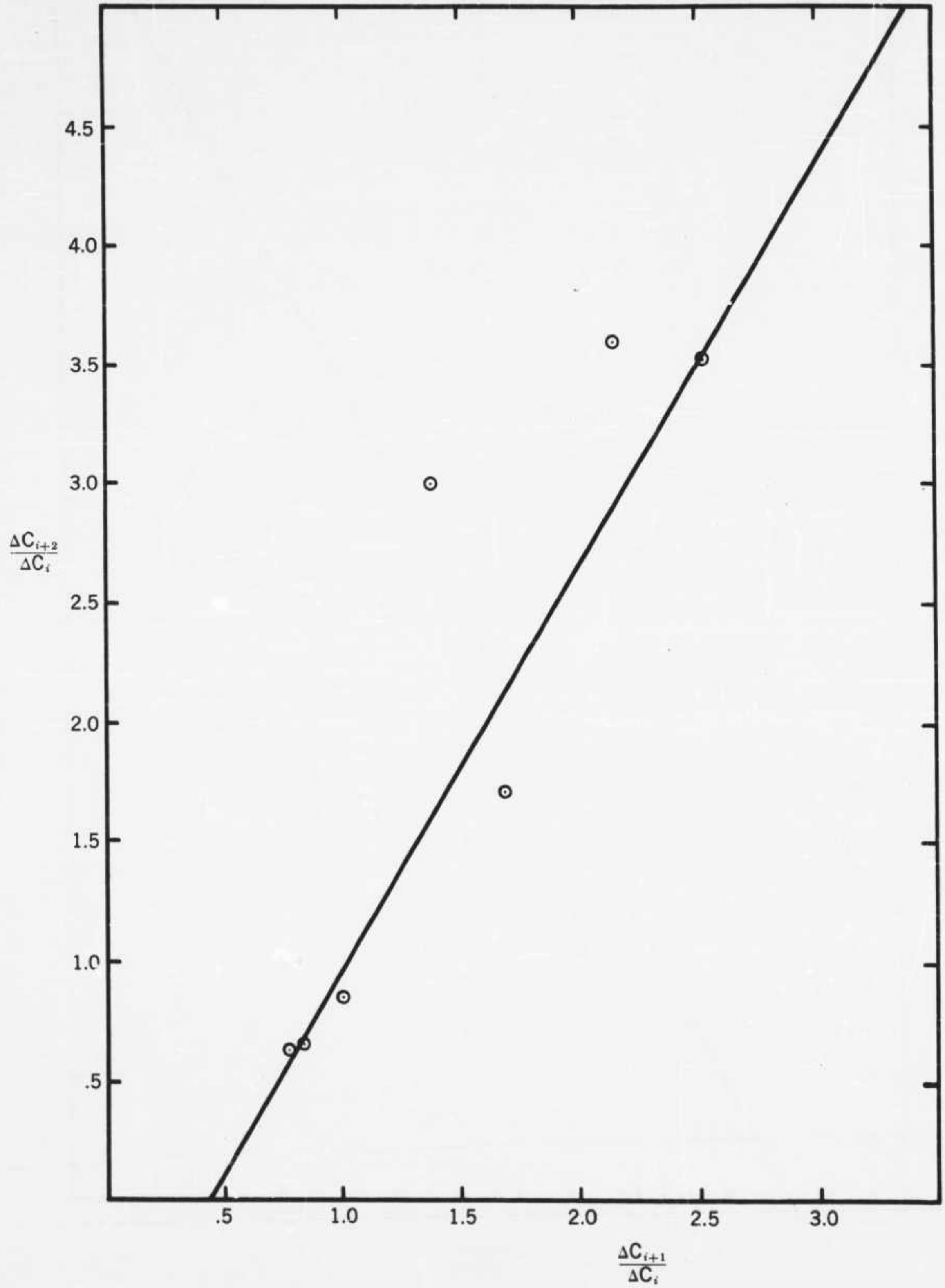


FIGURE B-7
PROJECT II

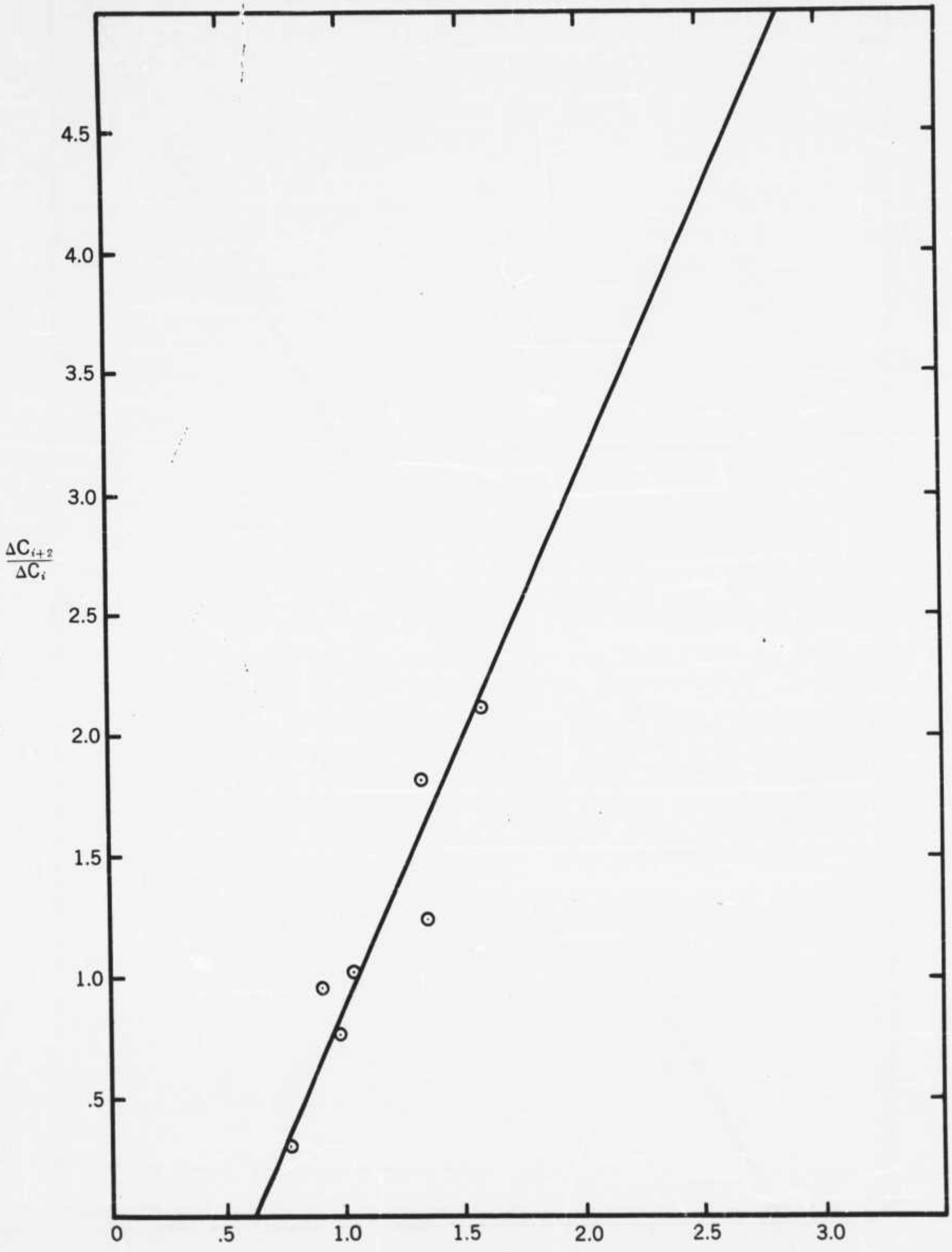


FIGURE B-8
PROJECT III

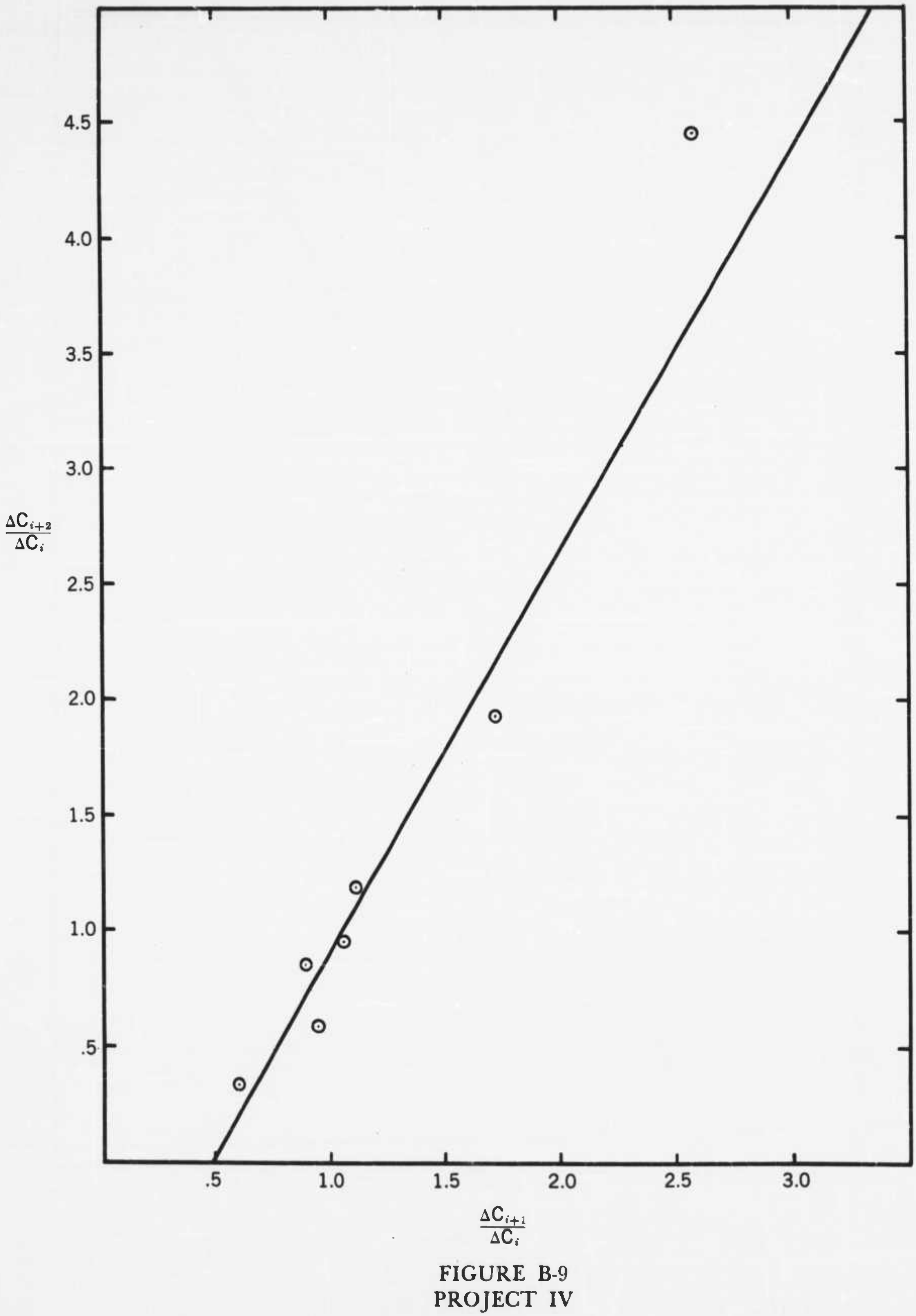


FIGURE B-9
PROJECT IV

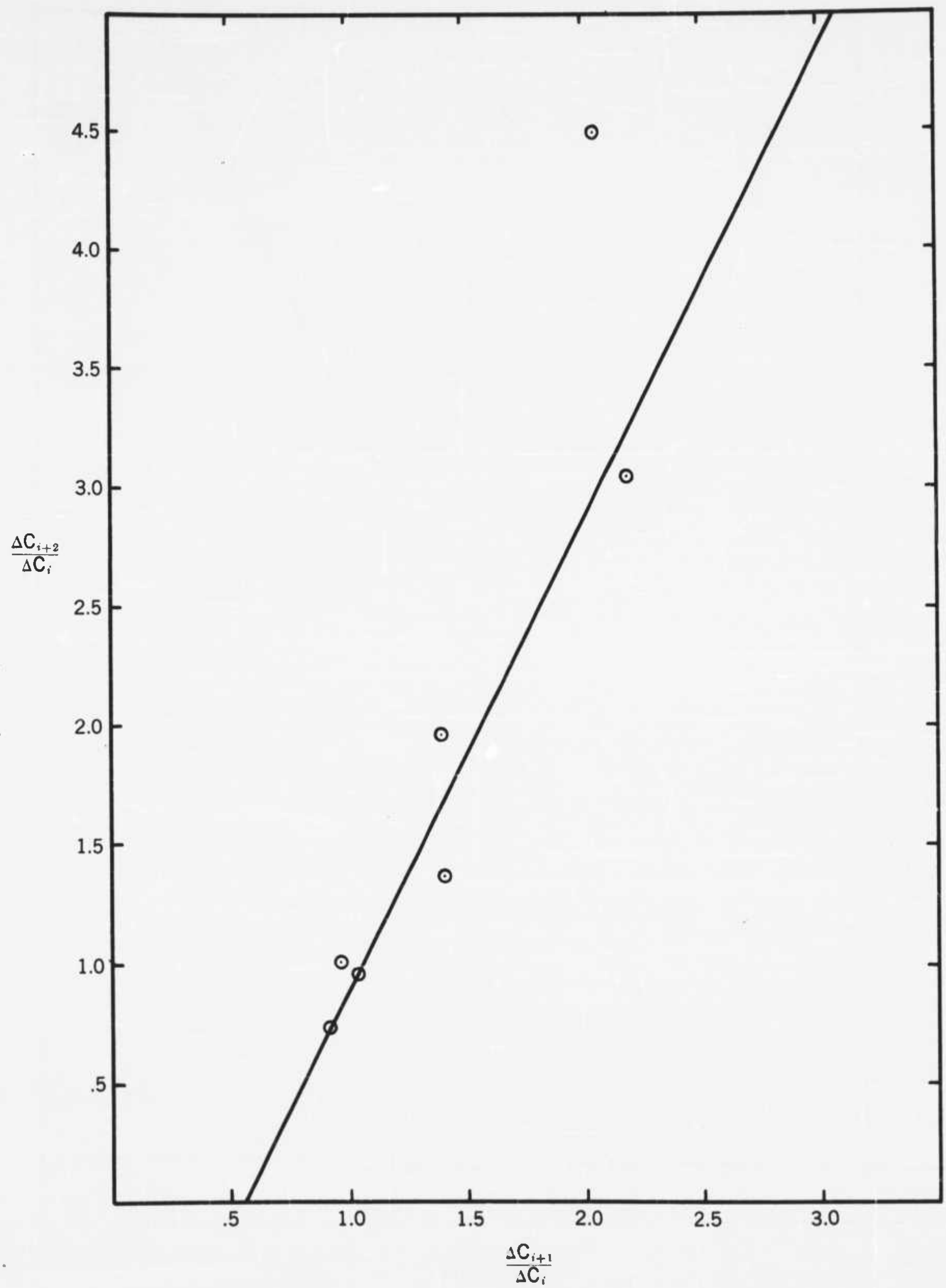


FIGURE B-10
PROJECT V

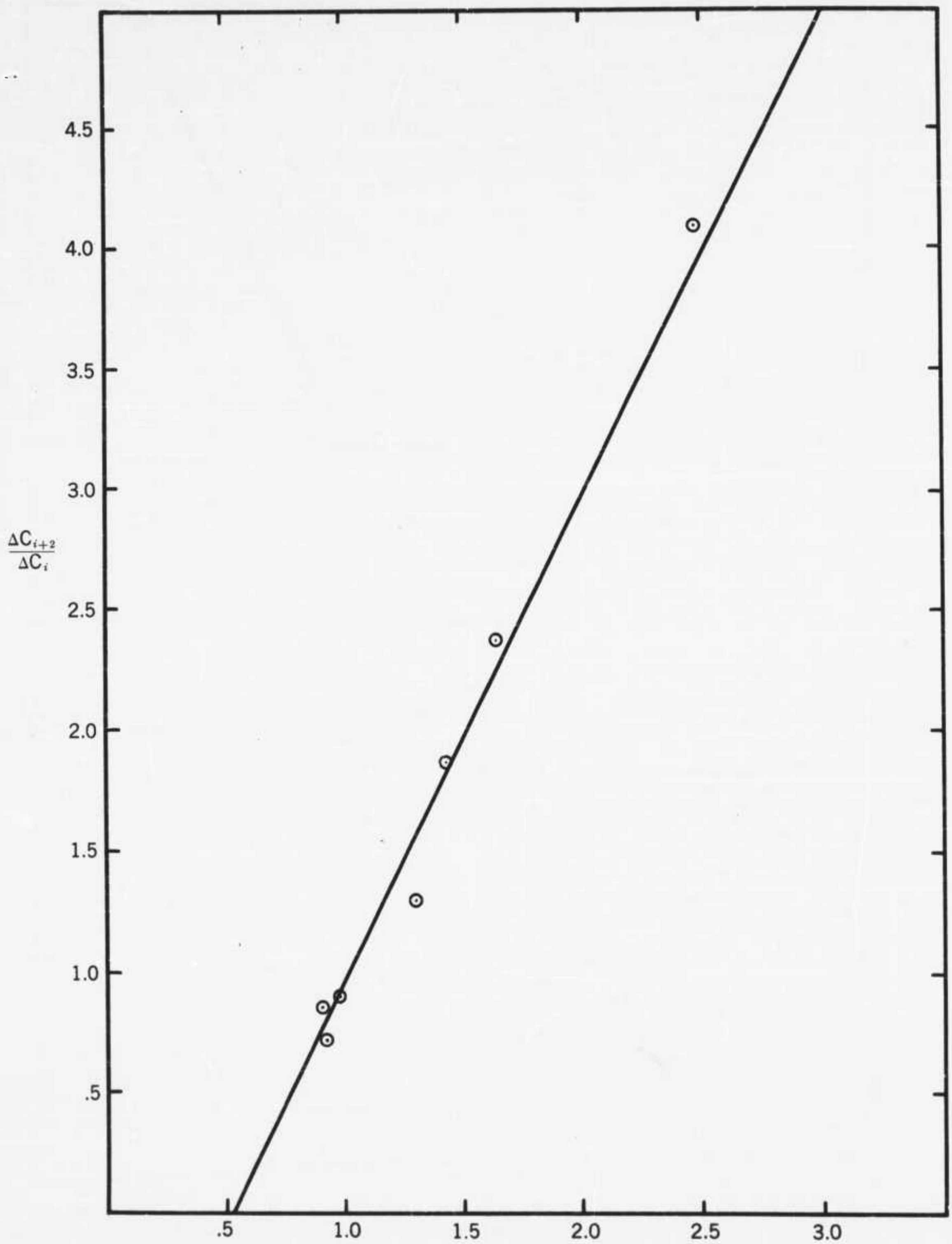


FIGURE B-11
PROJECT VI

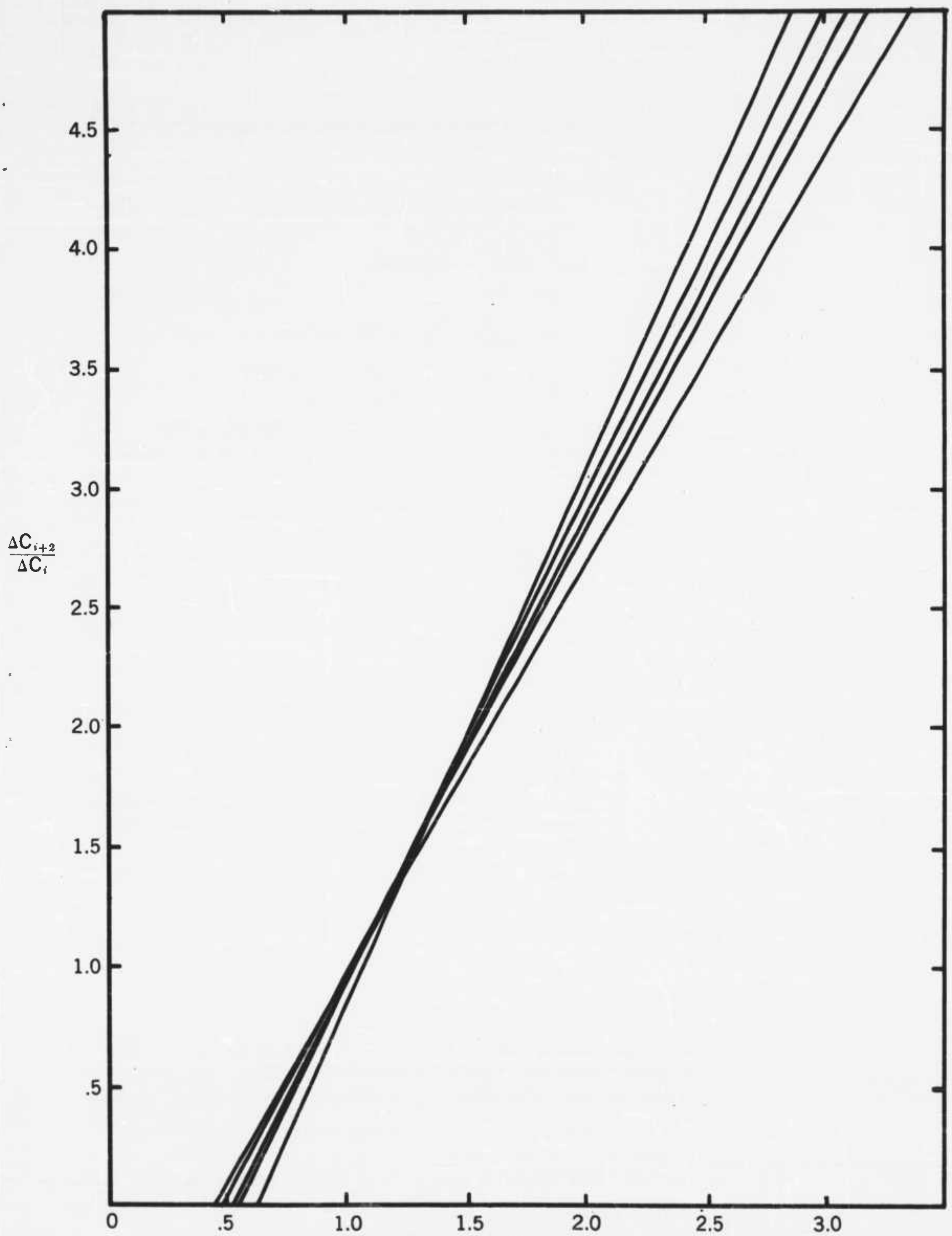


FIGURE B-12
PROJECTS I–VI

F_2 is the total effort put into applied research up to the same time. In terms of these

$$A = A_o e^{-k_1 F_1} \tag{11a}$$

$$B = e^{-k_2 F_2} \int_o^t k_1 E_1(t_1) A(t_1) e^{k_2 F_2(t_1)} dt_1 \tag{11b}$$

$$C = A_o - A - B \tag{11c}$$

If E_1 and E_2 are constant, these become

$$A = A_o e^{-k_1 F_1} \tag{12a}$$

$$B = \frac{k_1 F_1 A_o}{k_2 F_2 - k_1 F_1} (e^{-k_1 F_1} - e^{-k_2 F_2}) \tag{12b}$$

$$C = A_o \left[1 - \frac{k_2 F_2 e^{-k_1 F_1} - k_1 F_1 e^{-k_2 F_2}}{k_2 F_2 - k_1 F_1} \right] \tag{12c}$$

but it is not necessarily desirable for E_1 and E_2 to be held constant. In equation (11b), the factor $e^{k_2 F_2(t_1)}$ in the integral is equal to or greater than unity, since F_2 is necessarily positive. Hence

$$B \geq B_1 \tag{13}$$

where

$$\begin{aligned} B_1 &= e^{-k_2 F_2} \int_o^t k_1 E_1(t_1) A(t_1) dt_1 \\ &= e^{-k_2 F_2} \int_o^t \left(- \frac{dA}{dt_1} \right) dt_1 \\ &= e^{-k_2 F_2} (A_o - A) \\ &= A_o e^{-k_2 F_2} (1 - e^{-k_1 F_1}) \end{aligned} \tag{14}$$

and if we put

$$C_1 - A_o - A - B_1 = A(1 - e^{-k_1 F_1})(1 - e^{-k_2 F_2}) \tag{15}$$

then

$$C \leq C_1 \tag{16}$$

It follows that a knowledge of the total efforts F_1 and F_2 up to a certain time puts an upper limit C_1 to the total number of applications. How nearly this upper limit is reached depends on the timing. For example, if all the applied effort F_2 is used before any of the basic effort F_1, then equations (11) give

$$\begin{aligned} A &= A_o e^{-k_1 F_1} \\ B &= A_o (1 - e^{-k_1 F_1}) \\ C &= 0 \end{aligned}$$

and no useful results are obtained.

how to divide a fixed total effort between basic and applied research

The upper limit is reached if, and only if, all the basic research effort is completed before any of the applied effort is started. To do otherwise is therefore wasteful, although it may be required by other considerations.

We can now attack the problem of how to divide a fixed total effort between basic and applied research. Suppose that it is desired to divide a given total F between F_1 and F_2 so as to maximize C. If the research

can be done sequentially, this will reduce to the problem of maximizing C_1 subject to the condition that

$$F_1 + F_2 = F \tag{17}$$

To solve this problem, it will be convenient to put

$$B_1 = 1 - e^{-k_1 F_1} \tag{18a}$$

$$B_2 = 1 - e^{-k_2 F_2} \tag{18b}$$

Then

$$C_1 = A_o B_1 B_2 \tag{19}$$

and we can interpret B_1 as the fraction of A_o converted to B, and B_2 as the fraction of the B converted into C. Equations (18) can be inverted to give

$$F_1 = \frac{1}{k_1} \ln \frac{1}{1 - B_1} \tag{20a}$$

$$F_2 = \frac{1}{k_2} \ln \frac{1}{1 - B_2} \tag{20b}$$

The maximum problem is then to find B_1 and B_2 such that

$$B_2 dB_1 + B_1 dB_2 = 0 \tag{21}$$

for arbitrary dB_1 and dB_2 subject to the condition

$$\frac{1}{k_1} \frac{dB_1}{1 - B_1} + \frac{1}{k_2} \frac{dB_2}{1 - B_2} = 0 \tag{22}$$

This reduces to

$$\frac{k_1 (1 - B_1)}{B_1} = \frac{k_2 (1 - B_2)}{B_2} \tag{23}$$

as the equation which must be satisfied by the B's at the maximum. In order to compute with these equations, let us define

$$k = \sqrt{k_1 k_2} \tag{24}$$

and

$$\frac{k_1}{k} = \frac{k}{k_2} = \sqrt{\frac{k_1}{k_2}} \tag{25}$$

If we also put

$$\frac{k}{\lambda} = \frac{k_1(1 - B_1)}{B_1} = \frac{k_2(1 - B_2)}{B_2} \tag{26}$$

Then in terms of λ and ρ we find

$$B_1 = \frac{\rho\lambda}{1 + \rho\lambda} \tag{27a}$$

$$B_2 = \frac{\rho^{-1}\lambda}{1 + \rho^{-1}} \tag{27b}$$

$$B_1 B_2 = \frac{\lambda^2}{(1 + \rho\lambda)(1 + \rho^{-1}\lambda)} \tag{27c}$$

$$kF_1 = \rho^{-1} \ln (1 + \rho\lambda) \tag{27d}$$

$$kF_2 = \rho \ln (1 + \rho^{-1}\lambda) \tag{27e}$$

converting a fraction of a new field into applied results

To use these equations, suppose that we wish to convert a fraction of a new field into applied results. We set $B_1B_2 = \gamma$ in equation (27c) and solve for λ. The remaining equations then determine the efforts, F_1 and F_2, which should be put into basic and applied research, and the conversion fractions B_1 and B_2.

If the total effort is to be small, γ will be small, and we have

$$\lambda = B_1B_2 = \sqrt{\gamma} \tag{28a}$$

$$B_1 = \rho\lambda \tag{28b}$$

$$B_2 = \rho^{-1}\lambda \tag{28c}$$

$$kF_1 = \lambda \tag{28d}$$

$$kF_2 = \lambda \tag{28e}$$

This shows that a small effort should be divided equally between basic and applied research, no matter what the value of γ.

In the case of a large effort, say

$$\gamma = \frac{1}{1 + E} \tag{29}$$

where E is small, then λ is large, in fact

$$\lambda = \frac{\rho + \rho^{-1} + \sqrt{(\rho + \rho^{-1})^2 + 4}}{2E} \tag{30}$$

and the limiting forms are

$$B_1 = 1 - \frac{1}{\rho\lambda} + \cdots \tag{31a}$$

$$B_2 = 1 - \frac{1}{\rho^{-1}\lambda} + \cdots \tag{31b}$$

$$kF_1 = \rho^{-1} \ln \lambda + \rho^{-1} \ln \rho + \frac{1}{\rho^2\lambda} + \cdots \tag{31c}$$

$$kF_2 + \rho \ln \lambda + \rho \ln \rho^{-1} + \frac{1}{\rho^{-2}\lambda} + \cdots \tag{31d}$$

In the limit

$$\frac{F_2}{F_1} = \rho^2 = \frac{k_1}{k_2} \tag{32}$$

so that the two efforts are inversely proportional to the corresponding k's.

a first sharp rise in "getting the field started"

The main features of this model are shown graphically in Figures B-13 and B-14. In Figure B-13 is shown the total effort required to convert a given fraction of a field into applications. There is a first sharp rise in "getting the field started." Then for most of the conversion process the results rise nearly linearly with the effort. At very high

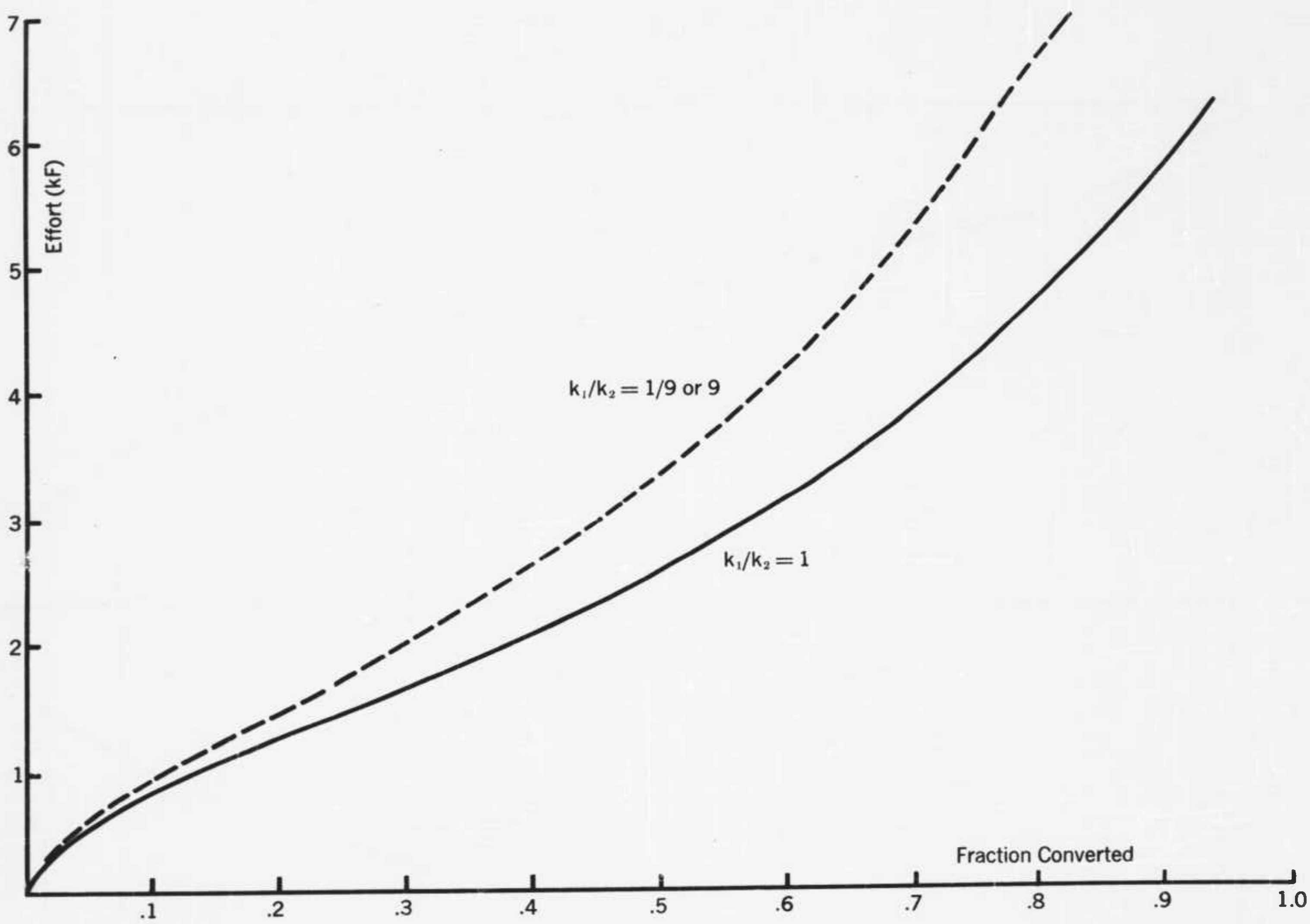


FIGURE B-13
Total Effort Required as Function of Degree of Conversion

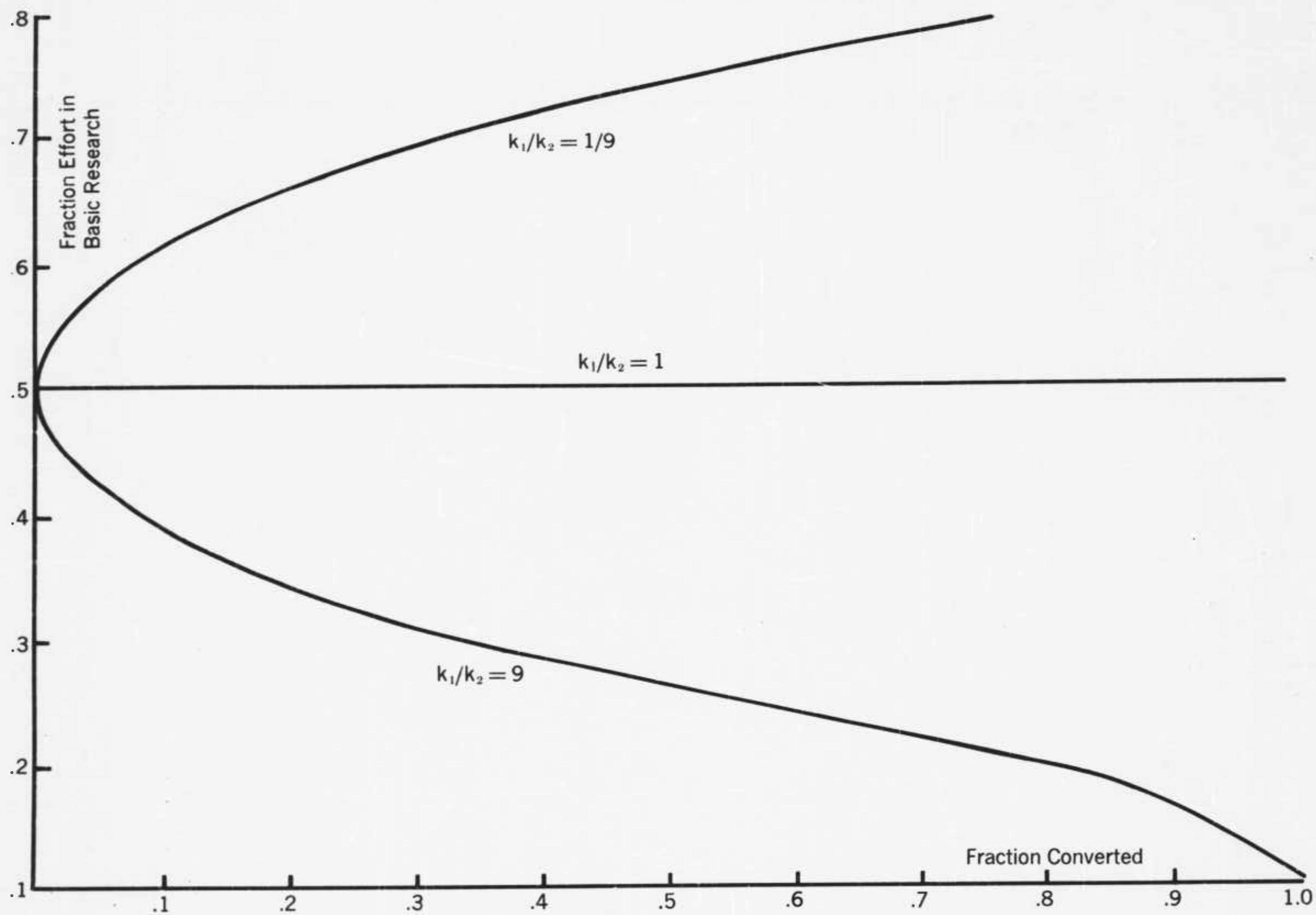


FIGURE B-14
Fraction Effort in Basic Research
as Function of Degree of Conversion

degrees of conversion, the law of diminishing returns sets in so that the effort per unit conversion rises very sharply, becoming infinite at 100% conversion.

In Figure B-14 is shown the optimum fraction of the effort which should be put into basic research. As we have pointed out previously, this is always 50% for small degrees of conversion, and approaches $k_2/(k_1 + k_2)$ at 100% conversion. For most of the intermediate range, the transition is approximately linear in the degree of conversion.

It is hard to believe that basic research is more than nine times as easy as applied research, the situation represented by the lowest curve in Figure B-14. If this model stands up, the implications are obvious.

Much additional work is required to elaborate this model. Three principal areas must be intensively investigated:

three principal areas must be intensively investigated

> The mathematics of the model must be elaborated, and the most practical method will probably involve the use of electronic computing machines to perform the numerical integrations.
>
> The relationship between time, manpower, etc., in the effort function requires considerable elaboration.
>
> Independent criteria for the measure of effectiveness must be developed before the results can be completely accepted.

Until this is done, it can only be stated that the model approach shows promise, and that the model developed is not inconsistent with the scanty data available.

Appendix C

Manpower Studies

Summary

Since 1910, research and development activities have grown at the rate of 10% per year, while the number of scientists and engineers has increased at the rate of 5% per year. If these trends persist, a serious shortage of technical manpower may develop in the near future.

In the past 25 years the number of science doctorates has increased at a rate comparable with other non-scientific fields. Barring major changes in educational policies, it now appears that for a more rapid growth in scientific manpower, the number of students in other educational disciplines will have to increase correspondingly.

At the present time, 2% of all engineers and scientists are engaged in basic research activities, 25% in research and development.

The major performers of basic research are educational institutions, which account for 60% of the total; industry accounts for 30% and Government for 10%.

Research and development expenditures per research worker average $25–30,000 in Government and industry, and $13–15,000 in educational institutions.

Publications in scientific journals are a useful measure of basic research activity. A strong correlation exists between number of publications and the scientific reputation of individual scientific workers.

Using publication rate as the measure of scientific productivity, we find that 20–30% of all scientists with Ph.D. degrees in astronomy, chemistry, and physics contribute over 80% of the basic research results in their respective fields of specialization.

Comparison of basic research expenditures in Government and industry indicates that large industrial firms in fields of high product obsolescence and rapid technological progress have increased basic research activities at a faster rate than Government agencies during the past decade.

The Navy Department is the most research-minded of the three armed services. With one-quarter of the research and development budget of the Department of Defense, the Navy Department accounts for two-thirds of the basic research activities performed in Government laboratories.

A significant increase in basic research effort can be achieved by expansion of the Contract Research Programs of Government agencies and private foundations. According to the Coordinating Committee of Science of the Department of Defense, budget increases of 70% are justified by the number of meritorious proposals rejected for lack of available funds.

Introduction

Basic research is performed by scientists and engineers with adequate educational background and professional experience. But not every competent scientist and engineer is engaged in basic research. As we will see in subsequent sections, basic research absorbs only a relatively small percentage of all qualified individuals. Applied research, development, production, administration, and teaching place much greater manpower demands on the scientific community.

estimate the basic research potential of the United States

The objective of this appendix is to estimate the basic research potential of the United States as measured by the availability of scientists and engineers. This problem has been the subject of many studies by Government agencies and private institutions. In recent years the National Science Foundation has been particularly active in this field. Most of these studies are unsatisfactory for our purpose because they do not distinguish basic research from other scientific activities. That such a distinction can be made is not generally conceded. It is often asserted that this distinction is artificial because the terms "basic" and "applied" refer to a continuous spectrum of activities ranging from work of a very fundamental nature to inconsequential gadgetry. While there undoubtedly exist borderline areas where subjective criteria must determine the side of the line on which a research project falls, this region of uncertainty is relatively narrow and does not interfere seriously with the classification of research. We are led to this conclusion by the following considerations:

> The results of most basic research studies are published in scientific journals. Security restrictions may delay publi-

cation, but seldom for more than a few years. Since editorial boards consist of competent scientists, there is remarkable agreement between scientific opinion and the editorial policy of the journals in each field of specialization. Scientific results not published in basic research journals can be assumed not to be of basic research nature.

Given a list of research projects, each one described in a paragraph or less, most scientists are in agreement as to which projects belong to basic and which to applied research.

Research Expenditures

As the first step in this study we will review research expenditures in the United States. Research expenditures are a practical and unambiguous measure of research activity. Since, however, these data were collected under varying conditions, and since differences of opinion exist as to the definition of basic research and applied research activities, we have examined two other factors correlated with research and development effort: a) number of scientists employed and b) number of scientists active in basic research, as measured by the number of papers published in scientific journals of recognized reputation.

the major performers of scientific research are government laboratories, industry, and educational institutions

The three major performers of scientific research in the physical sciences are Government laboratories, industry, and educational institutions. In 1953–54 the National Science Foundation conducted a survey of research and development activities in every sector of the economy.[1] A summary of the results is tabulated below:

TABLE C-I

Results of National Science Foundation Survey

Performers of Research	R & D Expenditures (M $)	Basic Research Expenditures (M $)
Government	970	47
Industry	3870	168
Educational and Non-Profit Institutions	460	205
Other	70	14
Total	5370	435

According to this survey, industry accounts for the bulk of the research and development effort, including both civilian and military projects

[1] 7th Annual Report, 1957, National Science Foundation, pp. 6–8

educational and other non-profit institutions are leaders in basic research

financed by the Department of Defense and other Government agencies.

Basic research represents 8% of research and development expenditures. In basic research, educational and other non-profit institutions are undisputed leaders. The sources of financial support for research activities are shown in Table C-II, based again on the National Science Foundation survey of 1953–54. Government and industry share almost equally in support of research, and academic institutions rely heavily on Government and industry sponsorship.

TABLE C-II

Sources of Research Funds

Sources	R & D Expenditures (M $)	Basic Research Expenditures (M $)
Government	2810	158
Industry	2370	179
Educational and Non-Profit Institutions	130	60
Other	50	38
Total	5370	435

Research and Development Personnel

Current Government estimates [2] place the number of scientists and engineers employed in the United States at 750,000. Of this total, 200–230,000 are engaged in research and development activities.[3, 4] The remainder are in production, teaching, administration, etc. Table C-III shows the percent of scientists and engineers in research and development by field of specialization.[5]

The employment of research and development personnel has been studied by the National Science Foundation[6] on the basis of 1953 data. Results are shown in Table C-IV.

[2] "Engineering and Scientific Manpower in the United States, Western Europe, and Soviet Russia," Joint Committee on Atomic Energy, 1956.

[3] Scientific Personnel Resources, National Science Foundation, 1955, p. 22.

[4] Reviews of Data on Research and Development, National Science Foundation, February, 1958.

[5] Scientific Personnel Resources, National Science Foundation, 1955, p. 22.

[6] Ibid, p. 20.

TABLE C-III

Scientists in Research and Development

Field	Percent of Scientists in R & D
Astronomers	37
Biologists	32
Chemists	45
Engineers	25
Geologists	58
Geophysicists	56
Mathematicians	15
Meteorologists	12
Physicists	47

TABLE C-IV

Employment Distribution of Research and Development Scientists and Engineers

Type of Employer	Percent
Government	17
Industry	68
Educational and Non-Profit Institutions	15

The comparison of Tables C-I and C-IV reveals that Government laboratories account for 18% of all research and development expenditures and for 17% of the technical personnel engaged in these activities; industry for 72% of research and development expenditures and 68% of the technical personnel; educational institutions for 9% of the expenditures and 15% of the personnel. An equivalent interpretation of these relationships is presented in Table C-V where it is shown that, according to these data, research and development expenditures per research worker are $25–30,000 per year in Government and industry and half this amount in educational and other non-profit institutions.

TABLE C-V

Research and Development Expenditures Per Research Worker

Type of Organization	Total R & D Expenditure	Research Personnel Employed	R & D Expenditures per Researcher
Government	$ 970 M	34–39,000	$25–29,000
Industry	3870 M	136–156,000	25–28,000
Educational and Non-Profit Institutions	460 M	30–35,000	13–15,000

The relatively lower cost of research conducted in educational institutions can be explained if one notes that members of academic staffs, even when their primary interest is research, devote considerable time to teaching. In addition, they rely on inexpensive student help and tend to favor research projects which do not require major outlays. Also to be noted are the lower overhead rates charged by non-profit institutions and their lower salary structure.

Scientific Potential

the number of doctorates granted has quadrupled (1932-1955)

The Association of Research Libraries publishes annually a complete list of doctoral degrees awarded by American universities. During the period 1932–1955 the number of doctorates granted each year has almost quadrupled (See Table C-VI).

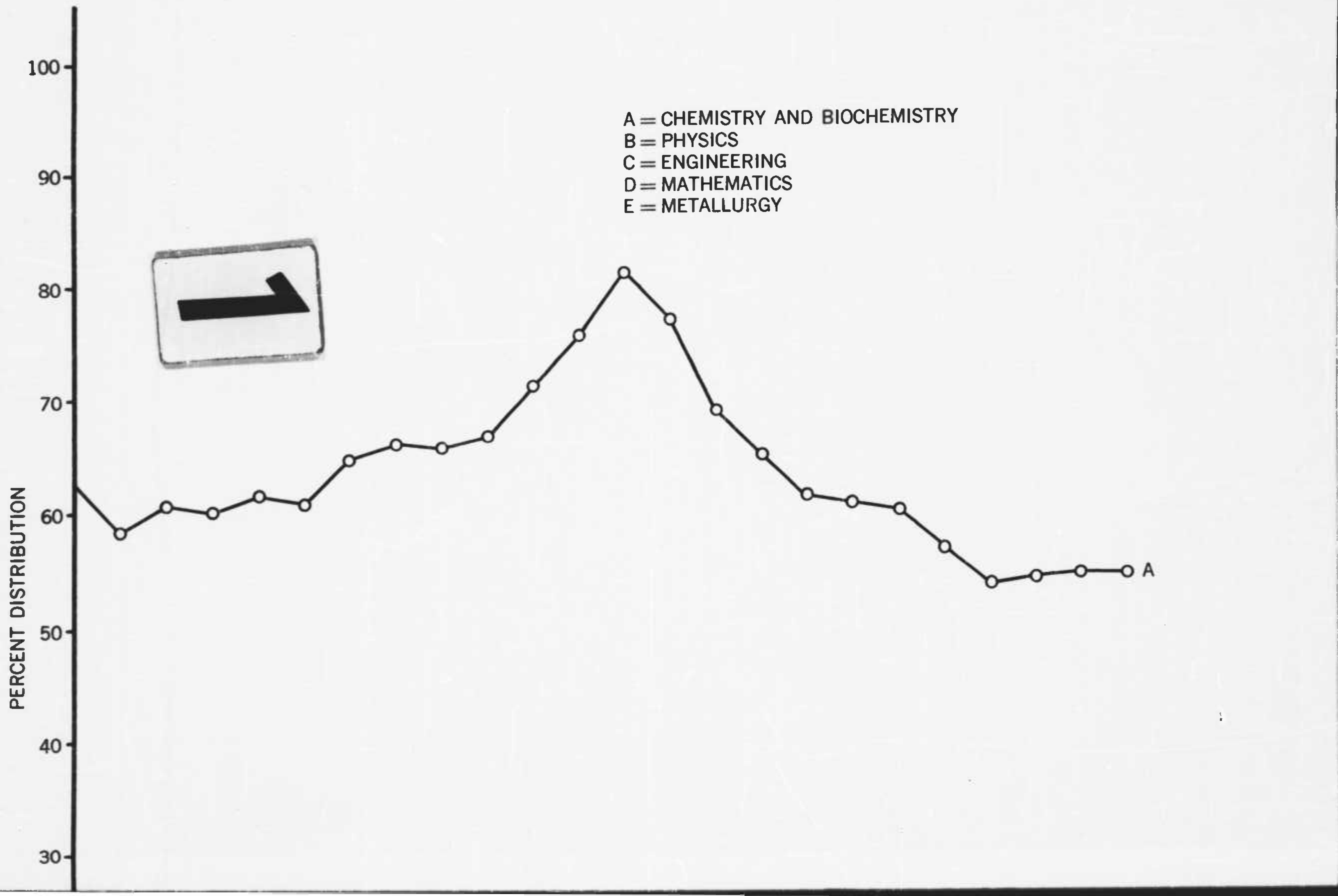
TABLE C-VI

Number of Doctoral Degrees Granted by American Universities

Year	No. of Degrees	Year	No. of Degrees
1932	2368	1944	2117
1933	2462	1945	1576
1934	2620	1946	1708
1935	2649	1947	2586
1936	2683	1948	3609
1937	2709	1949	4853
1938	2768	1950	6510
1939	2928	1951	7477
1940	3088	1952	7661
1941	3526	1953	8608
1942	3243	1954	9000
1943	2689	1955	8812

Table C-VII shows the percentage of doctorates awarded in the physical and biological sciences during the same period. The remarkable constancy of these percentages indicates that the increase in scientific manpower has paralleled the increase in other non-scientific fields.

Within the various scientific disciplines there have been some notable shifts in the fields in which doctorates have been awarded. The number of engineers, physicists, and metallurgists is increasing more rapidly than the number of chemists or mathematicians (See Figure C-1). Similar shifts have occurred within the biological and social sciences and within the humanities.


PERCENT DISTRIBUTION
100
90
80
70
60
50
40
30
A = CHEMISTRY AND BIOCHEMISTRY
B = PHYSICS
C = ENGINEERING
D = MATHEMATICS
E = METALLURGY
A
1

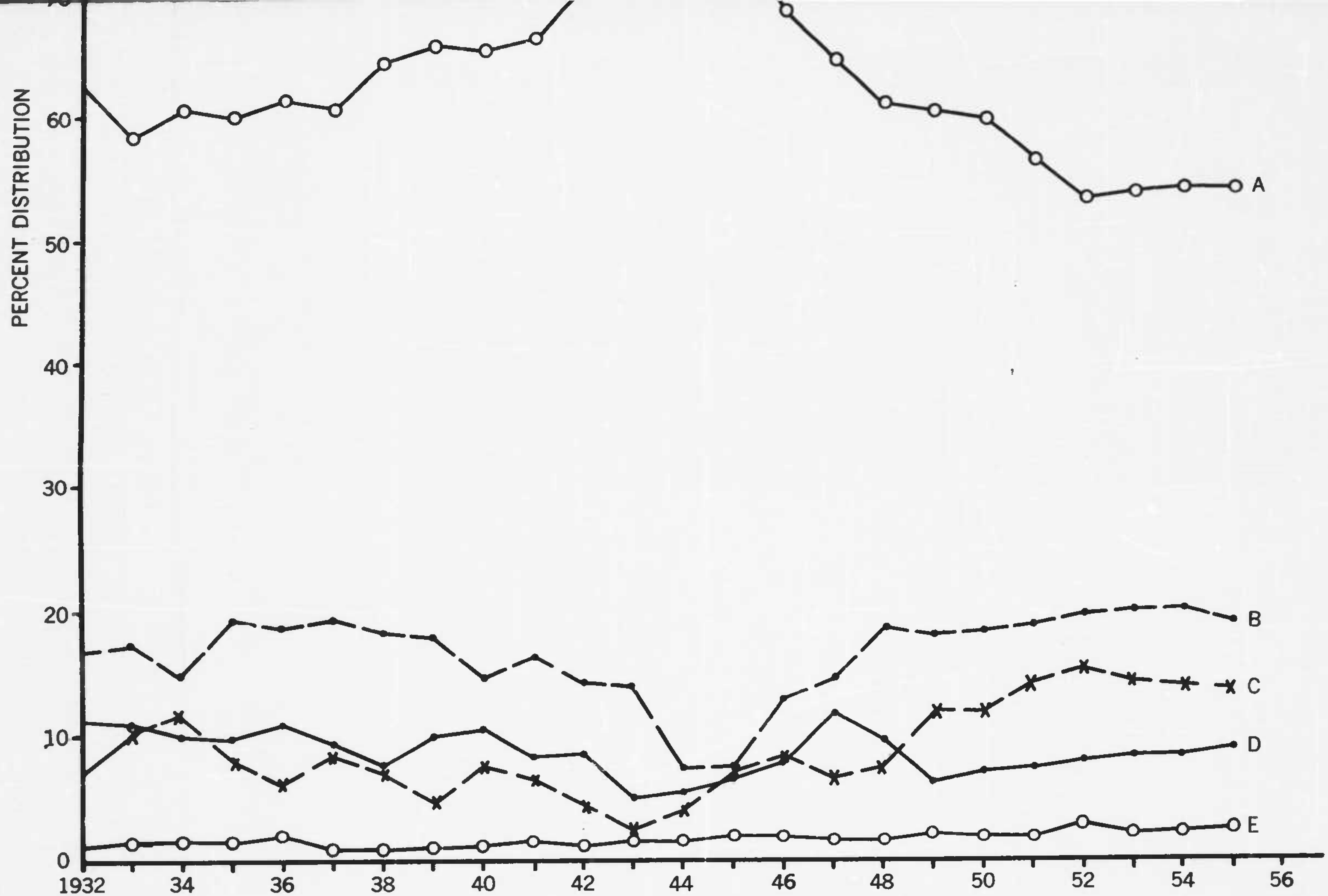


FIGURE C-1
Ph.D. DEGREES THE PHYSICAL SCIENCES

TABLE C-VII

Doctoral Degrees in the Physical and Life Sciences as Percent of All Doctoral Degrees Awarded

Year	Physical Sciences	Life Sciences
1932	30.5%	17.4%
1933	32.0	18.1
1934	34.7	20.5
1935	32.6	21.1
1936	32.0	21.2
1937	32.4	19.5
1938	28.7	22.4
1939	29.6	22.7
1940	31.0	24.0
1941	32.2	22.1
1942	29.7	22.9
1943	30.1	23.5
1944	31.6	21.3
1945	30.1	19.4
1946	29.4	18.5
1947	30.2	20.0
1948	34.0	21.4
1949	34.8	19.0
1950	33.4	19.1
1951	31.6	19.8
1952	32.2	18.9
1953	30.4	19.9
1954	29.4	20.5
1955	29.6	20.4

there has been no increase in relative number of science doctorates

The picture that emerges from these data is that the absolute number of science doctorates is growing, but the relative number of science doctorates is not. There have been significant shifts within each major field of knowledge, but during the past twenty-five years the balance between the physical and biological sciences and other disciplines has been preserved. One might conclude, therefore, that, barring major changes in educational policy, for a more rapid growth of scientific manpower, the number of students in other fields will have to be increased correspondingly.

No comparable data exists for bachelor's and master's degrees. However, estimates by the United States Department of Health, Education, and Welfare, Office of Education, indicate that the percentage of college graduates receiving doctorates has remained relatively constant at about 4% for several decades.

In the following pages we will attempt to estimate:

The number of scientists and engineers engaged in basic research.

The scientific and technical manpower potentially available.

The financial support needed to expand the basic research effort.

In order to achieve these objectives, it would be desirable to examine each scientific field individually. Lack of time and of reliable data in usable form has precluded this approach. We have limited ourselves to a few fields and extrapolated some of the results to the whole research community. We will first report on a study of astronomers. The small number of scientists active in this field has permitted us to identify them individually and review their scientific contributions.

Astronomers

The number of astronomers in the United States as been estimated in several ways:

1. The American Astronomical Society has over 700 members on its membership list. This number includes amateur astronomers as well as scientists whose primary interests are in other fields. Based on their recorded addresses, it appears that approximately 425 of the members of the Society are affiliated with university astronomy departments, observatories, etc.

2. In the 1954-55 survey, the National Register of Scientific and Technical Personnel reported 433 astronomers as holding doctor's degrees, or bachelor's degrees plus four years of scientific experience. Of these 433 astronomers, 83 were retired, inactive, on military duty, or otherwise not active professionally.

3. An estimate of the number of American scientists trained in astronomy can be computed in the following manner:

a) The number of Ph.D. degrees in astronomy granted by American universities is reported by the Association of Research Libraries.

b) The number of bachelor's degrees awarded in astronomy is 50% greater than the number of Ph.D. degrees. (According to the Office of Education, 153 bachelor's degrees and 102 Ph.D. degrees were awarded by United States universities during the period 1948–1954. Assuming that this proportion has remained constant in the past several decades, we find that two thirds of astronomers hold Ph.D. degrees. This ratio agrees with the findings of National Science Foundation studies.)

c) Astronomers retire from active professional work at age 68.

d) The mortality rate for astronomers can be established from actuarial tables.

e) The number of foreign-educated astronomers employed in the United States is balanced by the number of United States

educated astronomers employed abroad. (Of all recipients of Ph.D. degrees in astronomy during the period 1936-1955, 11% are now located outside the United States. Conversely, 9% of the astronomers residing in the United States were trained at foreign universities.)

Figure C-2 presents in graphical form the number of scientists with bachelor's or Ph.D. degrees in astronomy in the years 1913–1955.

From data collected by the National Register of Technical and Scientific Personnel, from *American Men of Science*, from university and observatory reports, and from Astronomical Society membership, we have located the place of employment of most of the active astronomers. Results of this analysis are given in Table C-VIII.

TABLE C-VIII

Place of Employment of Astronomers

	Astronomers Holding Ph.D. Degrees	All Astronomers
Academic Institutions	59%	54%
Government	13	14
Industry	5	13
Inactive	23	19

Excluding graduate students, we find that approximately 300 professional astronomers were active in basic research in 1955.

As a further check we have examined all papers published in the *Astrophysical Journal*, *Astronomical Journal*, *Nature*, *The Physical Review*, *Proceedings of the Astronomical Society of the Pacific*, and *Monthly Notes*, in the years 1953–56. A total of 203 astronomers residing in the United States published one or more papers (as sole authors or co-authors) in the four-year period. Table C-IX shows the number of astronomers who published one, two, three, etc. papers during this period in the journals considered.

TABLE C-IX

Frequency Distribution of Publication in Astronomy By U. S. Astronomers 1953–1956

Papers Published	Number of Astronomers
1	88
2	22
3	23
4	20
5	16
6	11
7	1
8	8
9 or more	14

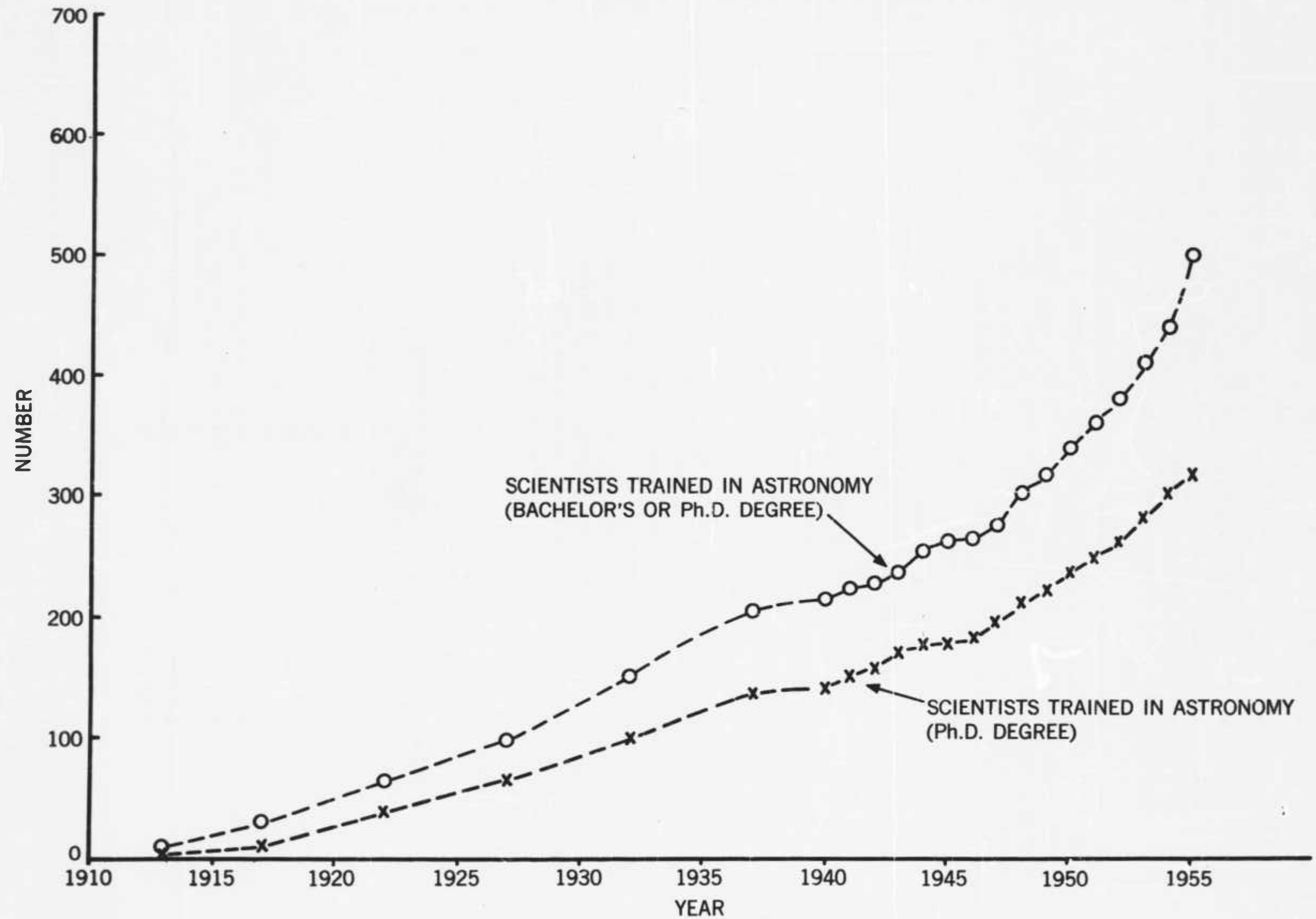


FIGURE C-2
NUMBER OF SCIENTISTS TRAINED IN ASTRONOMY

Physicists

Membership in the American Physical Society exceeds 12,000. Estimates of the number of physicists active in the United States range upward from 20,000.

The number of physicists holding Ph.D. degrees can be computed from data collected by the Association of Research Libraries, correcting for mortality rate and retirement age. Figure C-3 presents the number of physicists with Ph.D. degrees active during the years 1936–1956. Physicists aged 68 and over are not included in the total nor those now employed in the United States who received their doctoral degree in foreign universities. American physicists who have switched to other professions or reside abroad have not been subtracted.

Any extrapolation of the curve in Figure C-3 is subject to large uncertainties. If the number of degrees granted each year were to remain at the present level — and it probably will not — the total number of Ph.D. physicists would level off in twenty to thirty years at 20,000. If instead one were to extrapolate the rate of increase in the number of Ph.D.'s awarded annually and assume that physicists would continue to represent 20% of all physical scientists, and physical scientists 30% of all doctoral degrees granted, then the figure of 20,000 physicists would be reached before 1970.

before 1970 . . .
20,000 *physicists*

Research Activity — Physicists

The National Scientific Register, under sponsorship of the National Science Foundation, has collected detailed information on the activities and background of trained scientific workers. We have examined the data cards for all physicists with a doctoral degree. The 5202 physicists employed full-time are distributed by employment as shown in Table C-X.

TABLE C-X

Employment of Ph.D. Physicists — National Scientific Register

Type of Employer	No. of Physicists	Percent of Total
Educational and Non-Profit Institutions	2838	54.5
Government	523	10.1
Industry	1770	34.0
Other	71	1.4
	5202	100.0

The primary employment function of each physicist as reported by the National Science Foundation is shown in Table C-XI. Of all physicists reporting, 50.4% classify themselves primarily as researchers, 23.0% as teachers, and the remainder as engaged in other pursuits which are not strictly scientific in nature.

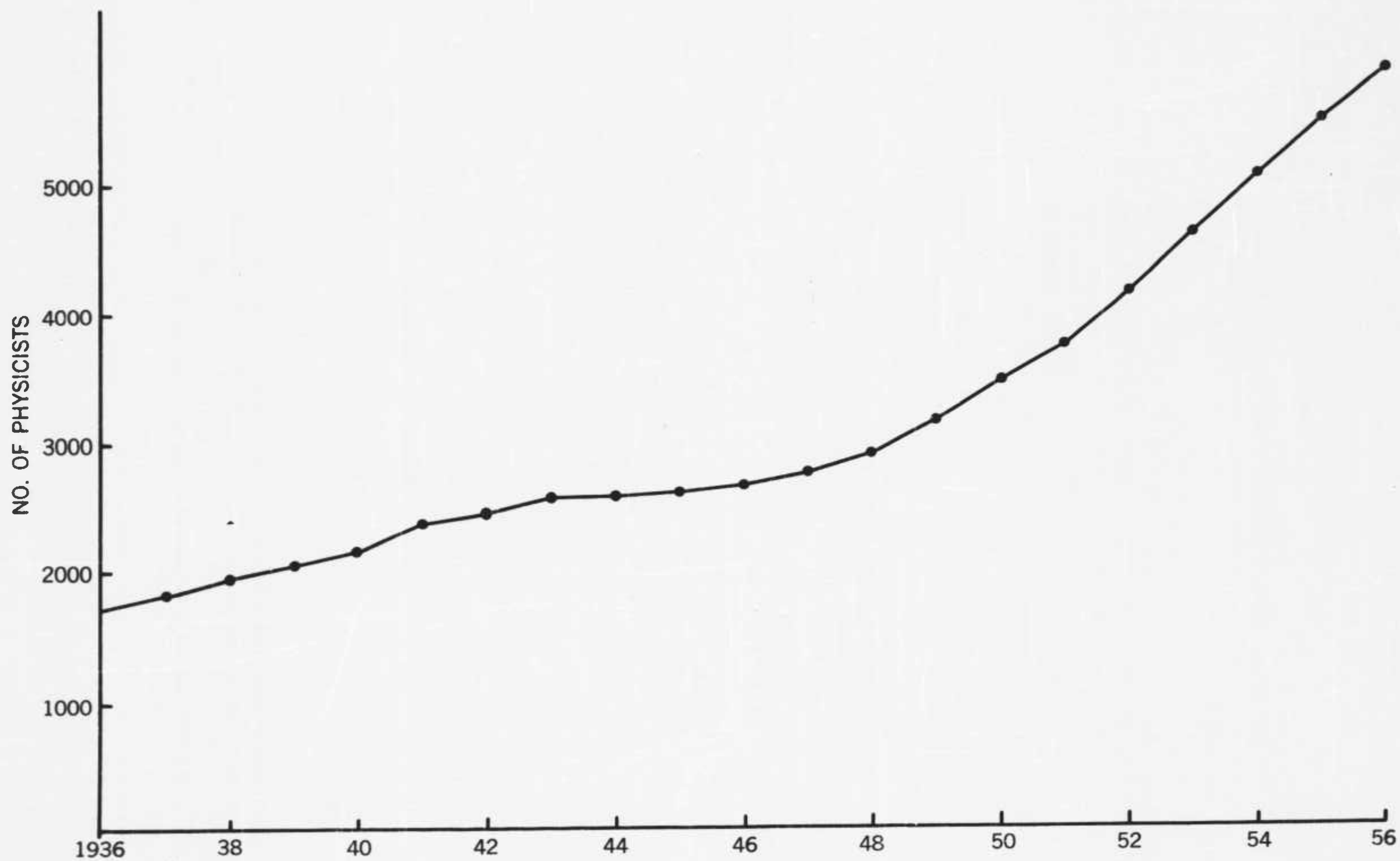


FIGURE C-3
ESTIMATED NUMBER OF U. S. SCIENTISTS
WITH Ph.D DEGREE IN PHYSICS

TABLE C-XI

Primary Employment Function

	Research	Develop-ment	Teaching	Management or Administrative	Technical Services
Education	1268	105	1163	249	15
Government	326	13	3	154	22
Industry	969	252	2	472	68

These results are not necessarily objective; they may be influenced by what each scientist wishes he were doing, rather than by what he is actually doing. University professors, for example, may overestimate their research activity; similarly, scientists employed by industry or in Government service may exaggerate their management or administrative duties. The inescapable conclusion is, however, that research, particularly basic research, is not the only activity of trained scientists.

results may be influenced by what the scientist wishes he were doing

For improved reliability of this information, it would be useful to identify and interview each physicist and estimate his present and potential contribution to basic research. This approach could not be pursued within the time limit of our study. Instead we have examined publications as a measure of basic research potential.

Basic Research Publications — Physicists

Scientists engaged in basic research publish their findings in scientific journals. A scientist who has not submitted a research paper to a recognized scientific publication for some years is not likely to be devoting more than a fraction of his time to basic research. We have considered the publication rate of all physicists who obtained their doctoral degree in an American university in 1936, 1941, 1946, and 1951. The frequency distribution of their most recent publication in *The Physical Review*, the journal where most fundamental discoveries in physics are reported, is shown in Figures C-4 through C-7. The figures show that 47% of all 1951 graduates have published in *The Physical Review* in the last five years, 30% of the 1946 graduates, 18% of the 1941 graduates, and 15% of the 1936 graduates. The decrease of publication rate with age can be explained by the assumption that recent graduates are strongly research-minded; in time many will drift away from basic research.

recent graduates are strongly research-minded

We conclude that 20–30% of the physicists holding Ph.D. degrees are active in basic research and contribute to the scientific literature. Their individual contributions vary greatly.

Relation Between Publication Rate and Scientific Competence

The most widely accepted measure of the scientific competence of an individual is the one agreed upon by colleagues acquainted with his achievements and his working habits. These opinions may not always

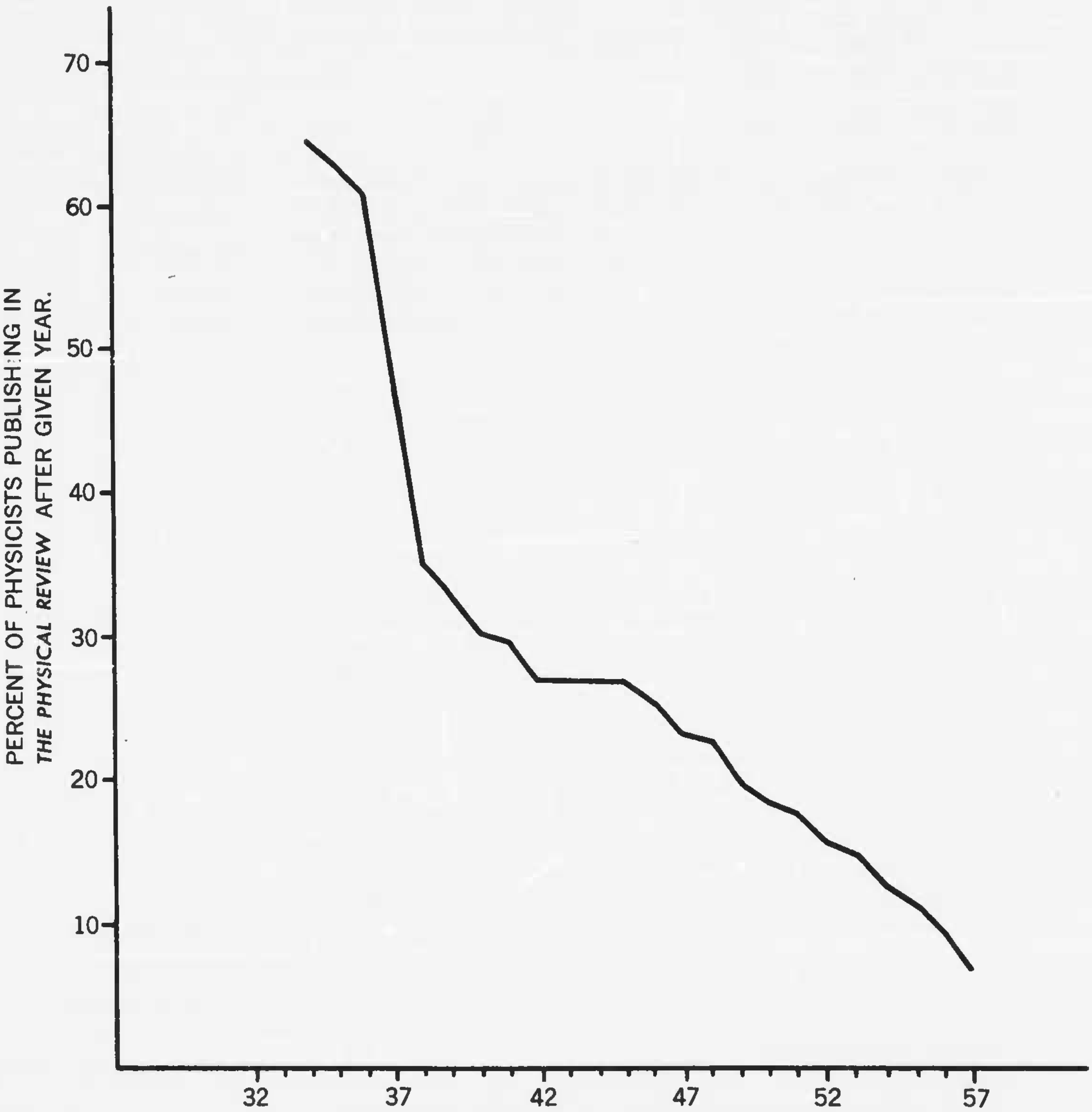


FIGURE C-4
PHYSICISTS (Ph.D. 1936)
PHYSICISTS ACTIVE IN BASIC RESEARCH
AS MEASURED BY PUBLICATIONS IN
THE PHYSICAL REVIEW.

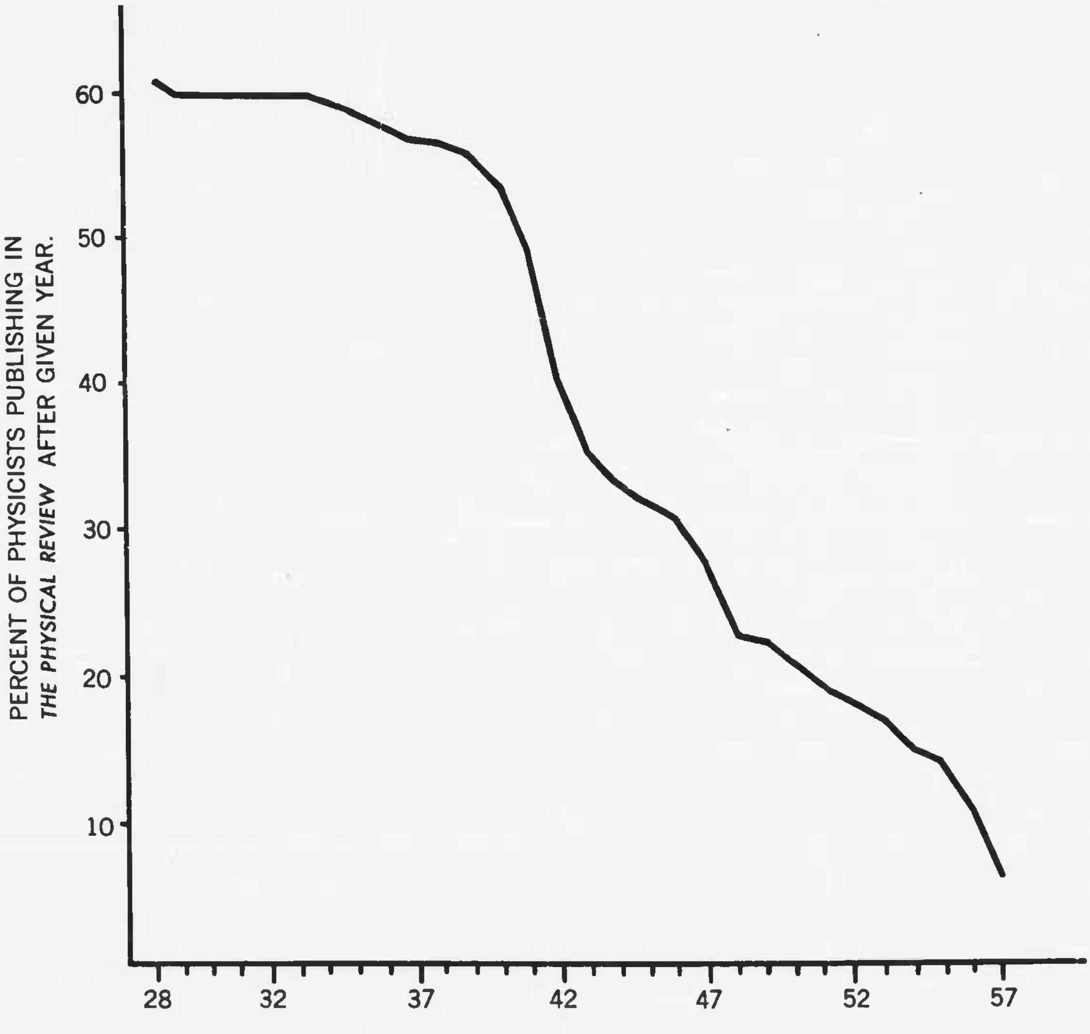


FIGURE C-5
PHYSICISTS (Ph.D. 1941)
PHYSICISTS ACTIVE IN BASIC RESEARCH
AS MEASURED BY PUBLICATIONS IN
THE PHYSICAL REVIEW.

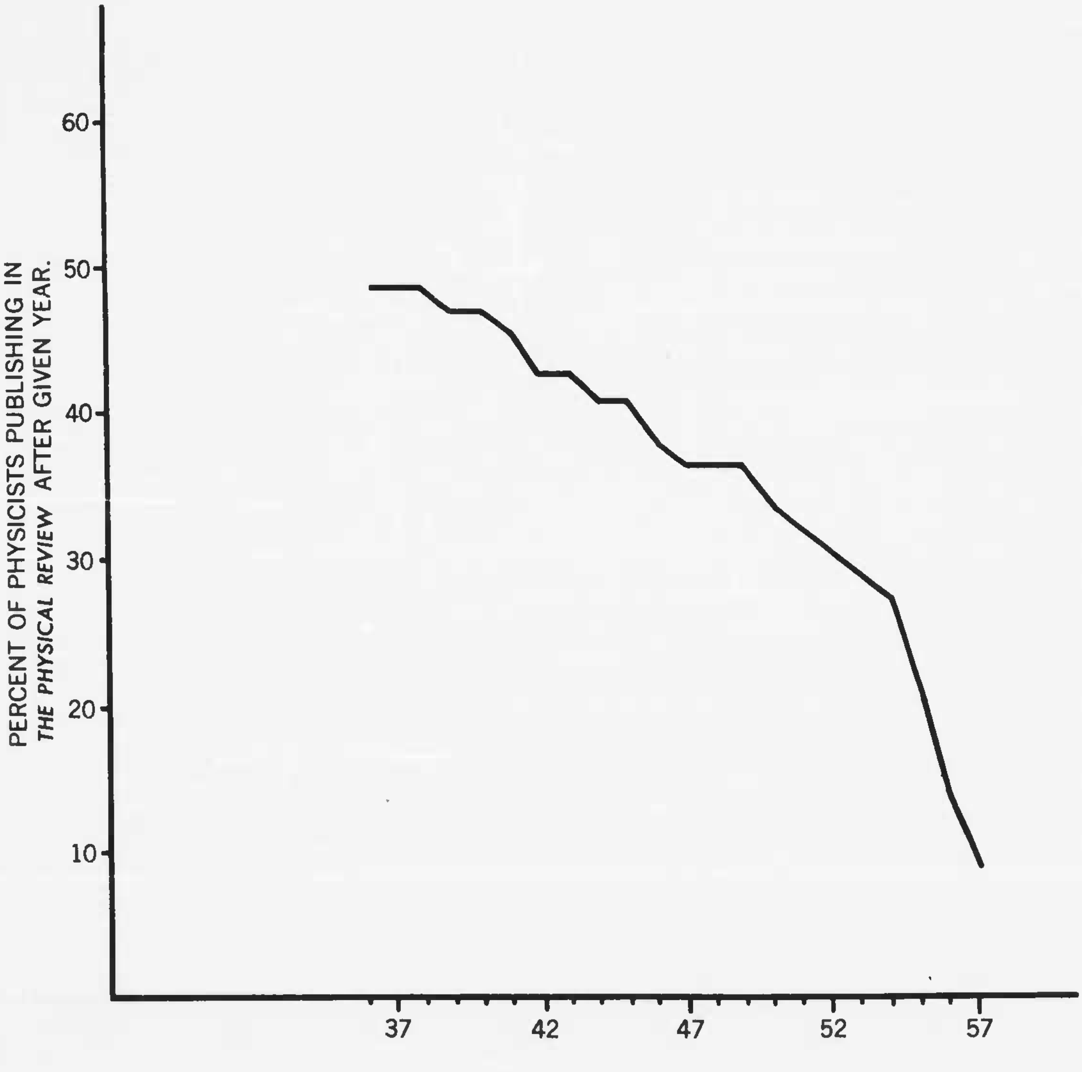


FIGURE C-6
PHYSICISTS (Ph.D. 1946)
PHYSICISTS ACTIVE IN BASIC RESEARCH
AS MEASURED BY PUBLICATIONS IN
THE PHYSICAL REVIEW

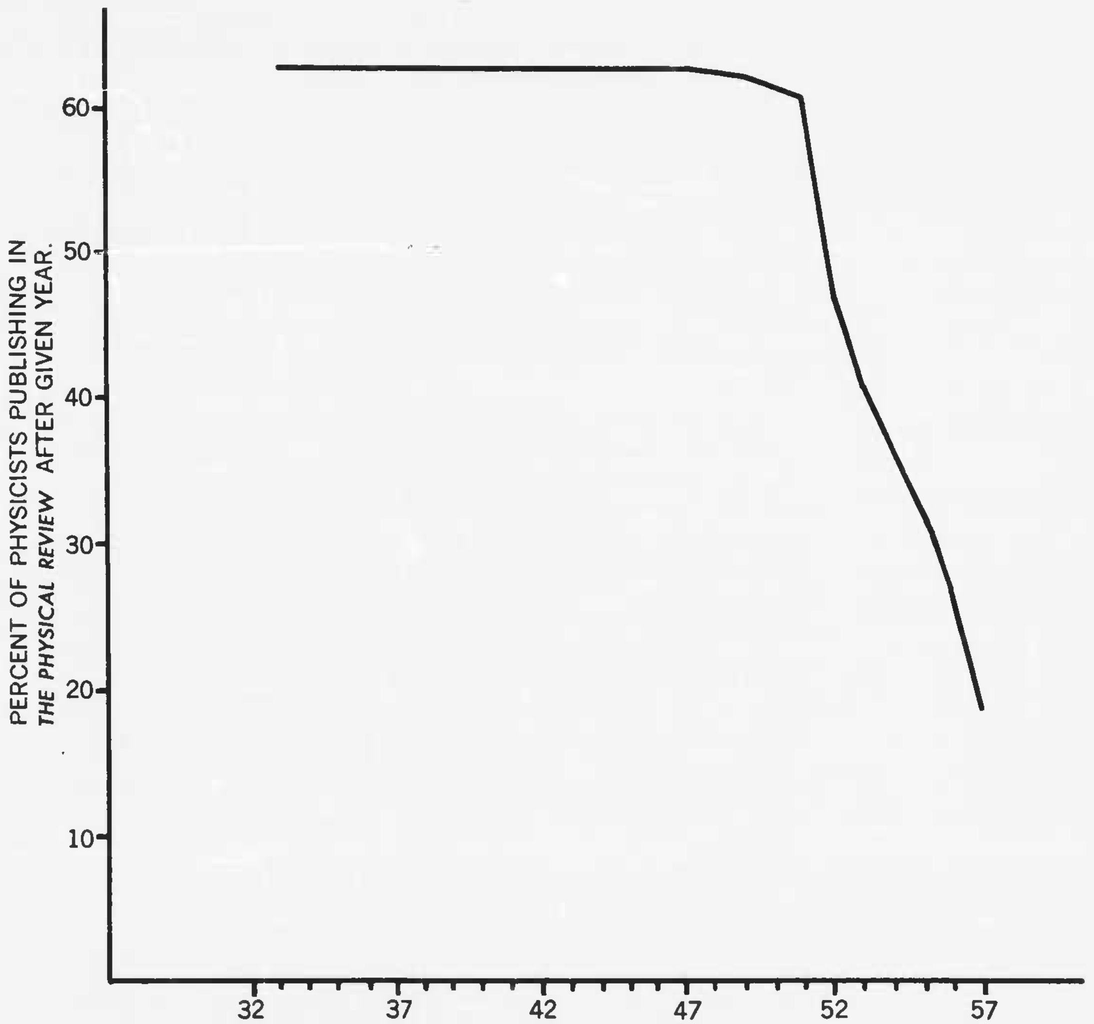


FIGURE C-7
PHYSICISTS (Ph.D. 1951)
PHYSICISTS ACTIVE IN BASIC RESEARCH
AS MEASURED BY PUBLICATIONS IN
THE PHYSICAL REVIEW

be unanimous and may at times prove erroneous; in general, however, they are reliable. Promotions, salary levels, and scientific recognition ultimately rest on these personal judgments. We have not had the opportunity to conduct opinion surveys among scientists and have relied instead on comparable ratings. The Institute of Physics, for example, elects some of its members to fellowship. The criteria for this selection are not clearly expressed in the by-laws of the Society. They are based on scientific competence as understood within the scientific community. Election to the National Academy of Science is a significant honor bestowed for outstanding scientific achievements.

We have examined publication rates in *The Physical Review* of fellows of the Institute of Physics, members of the Academy of Science, and other physicists. The sample analyzed consists of all physicists who obtained their Ph.D. degree in 1936, 1941, 1946, and 1951. Figures C-8 through C-12 are histograms of the average number of publications of fellows of the Institute of Physics and of non-fellows. The number of publications by members of the Academy of Science of the Class of 1936 is shown separately. Too few of the younger men (Classes of 1941, 1946, and 1951) are members of the Academy to justify presenting comparable graphs for later years.

striking difference in the publication rate of fellows and of non-fellows

There is a striking difference in the publication rate of fellows and of non-fellows for every one of the four graduating classes considered. The very high publication rate of the Class of 1951 is due, in part, to the fact that many potential fellows have not yet been elected by the Society. Their inclusion within the non-fellow group tends to raise the average publication rate of fellows (only very outstanding young men belong to this group) and of non-fellows (this group includes men who will soon be advanced to fellowship). Figure C-12 shows that members of the Academy of Science have an even higher publication rate. They publish almost twice as many papers as fellows of the Institute of Physics. These results — that "publication rate" is strongly correlated with scientific recognition — are in agreement with the findings reported by Shockley[7] Dennis[8], and Fisher[9]. Similar results were obtained from the study of astronomers: the publication rate of members of the National Academy of Science is four times higher than the publication rate of other astronomers.

[7] William Shockley, "On the Statistics of Individual Variations of Productivity in Research Laboratories," Proceedings of the IRE, Vol. 45, pp. 279-290; March, 1957.

[8] Wayne Dennis, "Bibliography of Eminent Scientists," Scientific Monthly, Vol. 79, pp. 180-183; September, 1954.

[9] J. C. Fisher, "Who Does Basic Research in Industry," General Electric Research Laboratory, Schenectady, New York; private communication.

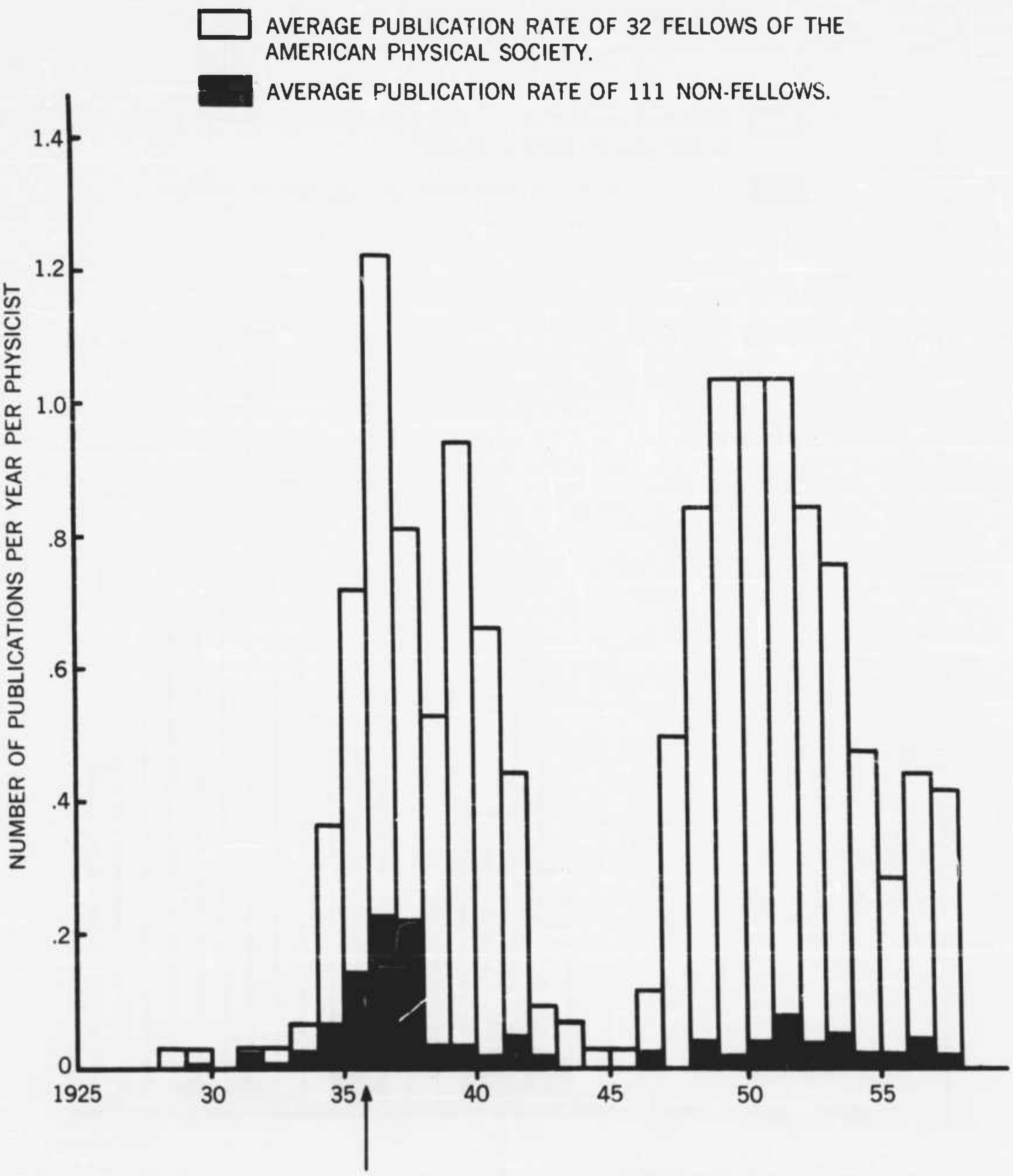


FIGURE C-8
PUBLICATION RATE IN *THE PHYSICAL REVIEW*
OF PHYSICISTS WHO OBTAINED Ph.D. IN 1936

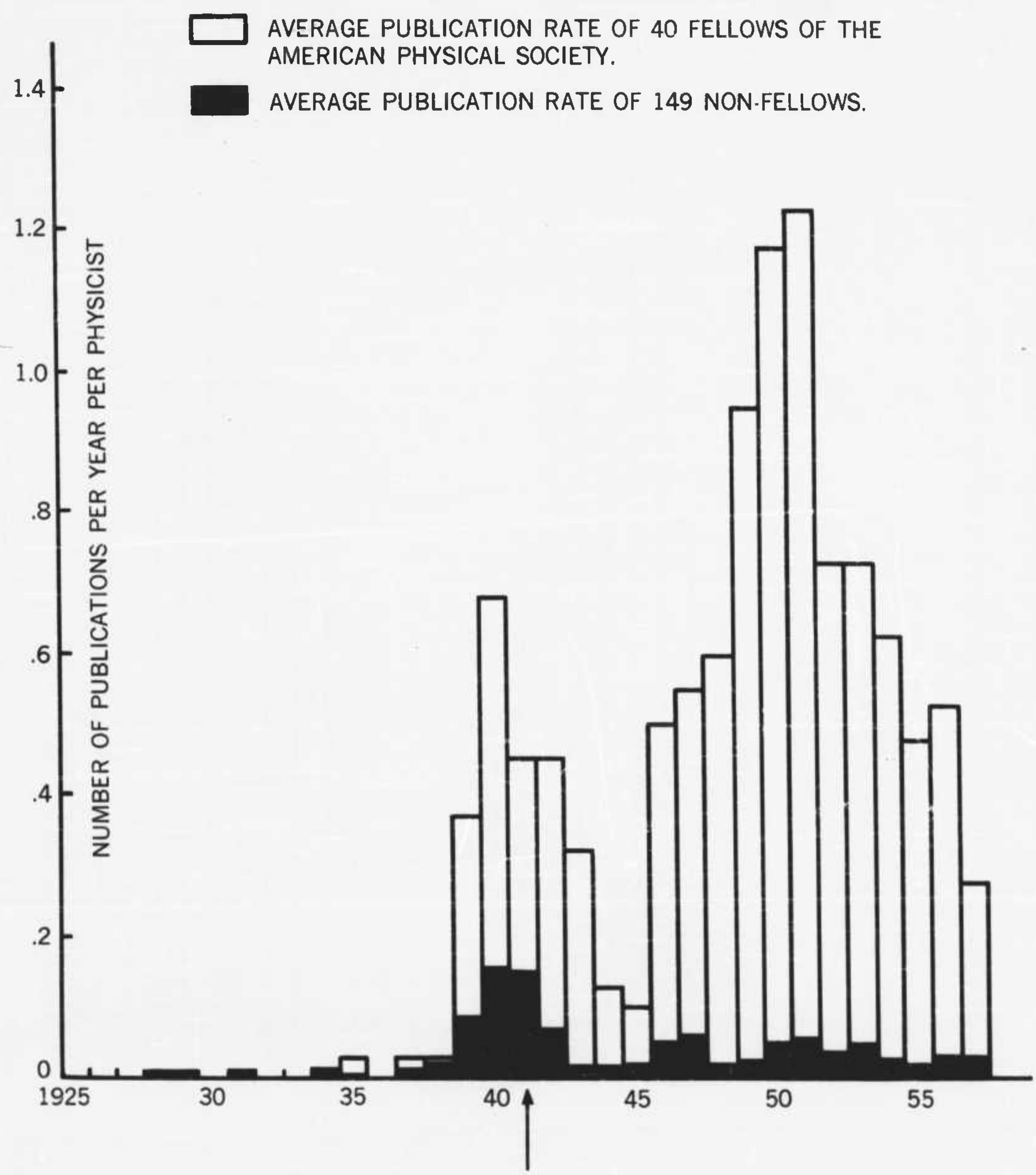


FIGURE C-9
PUBLICATION RATE IN *THE PHYSICAL REVIEW* OF PHYSICISTS WHO OBTAINED Ph.D. IN 1941

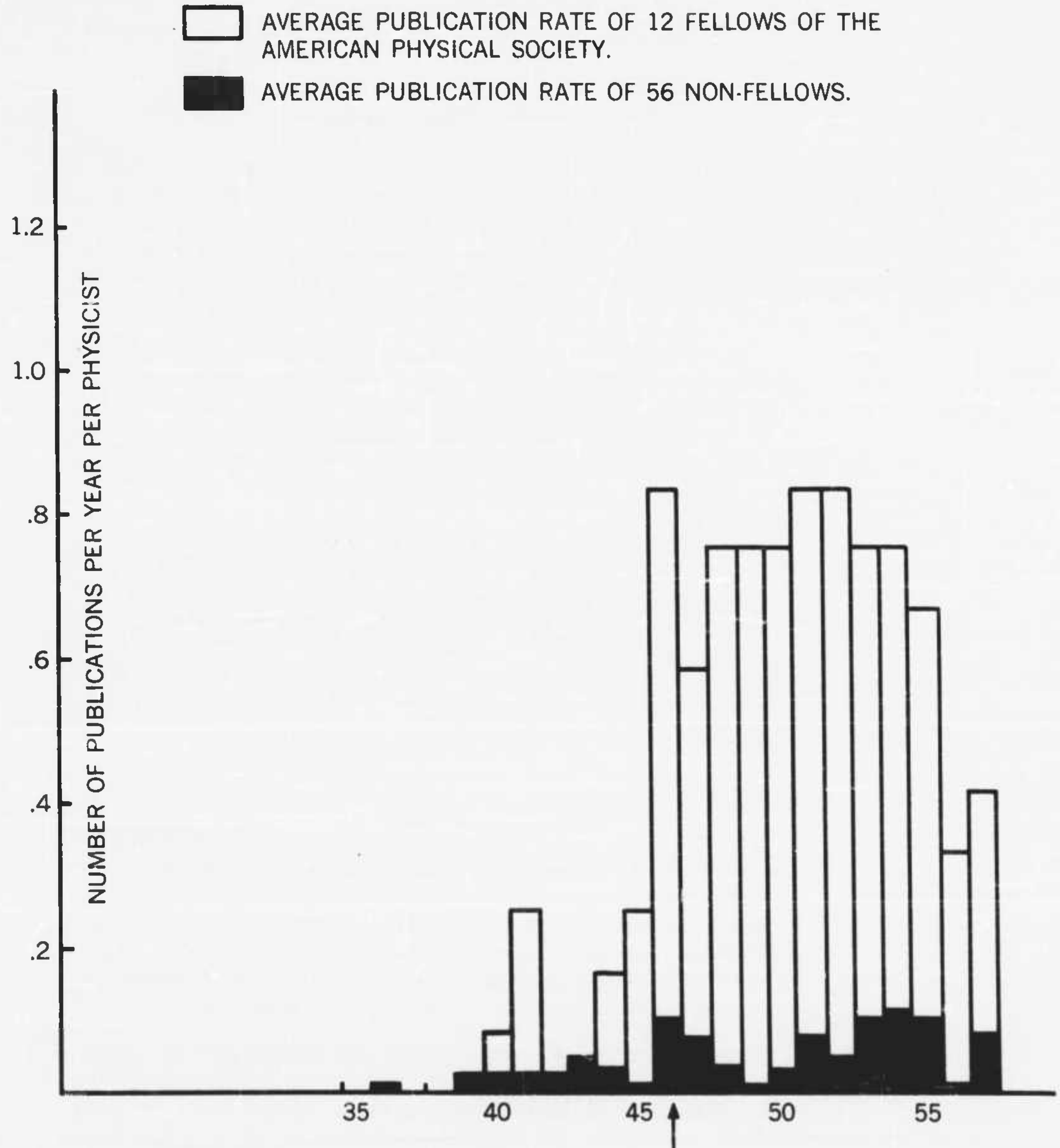


FIGURE C-10
PUBLICATION RATE IN *THE PHYSICAL REVIEW*
OF PHYSICISTS WHO OBTAINED Ph.D. IN 1946

We conclude that publication rate is a useful measure of scientific attainments. Corroborative evidence has been obtained by correlating publication rate with:

- Receipt of research grants
- Academic rank
- Salary level
- Number of graduate students supervised.

publication rate is one index of individual competence

We do not mean to imply that routine ranking devices such as publications can provide reliable indices of the competence of an individual. The factors determining research effectiveness are too numerous and their significance is little understood. Our object is to estimate how many scientists contribute most of the basic research results, not to develop an absolute scale for ranking individual scientists.

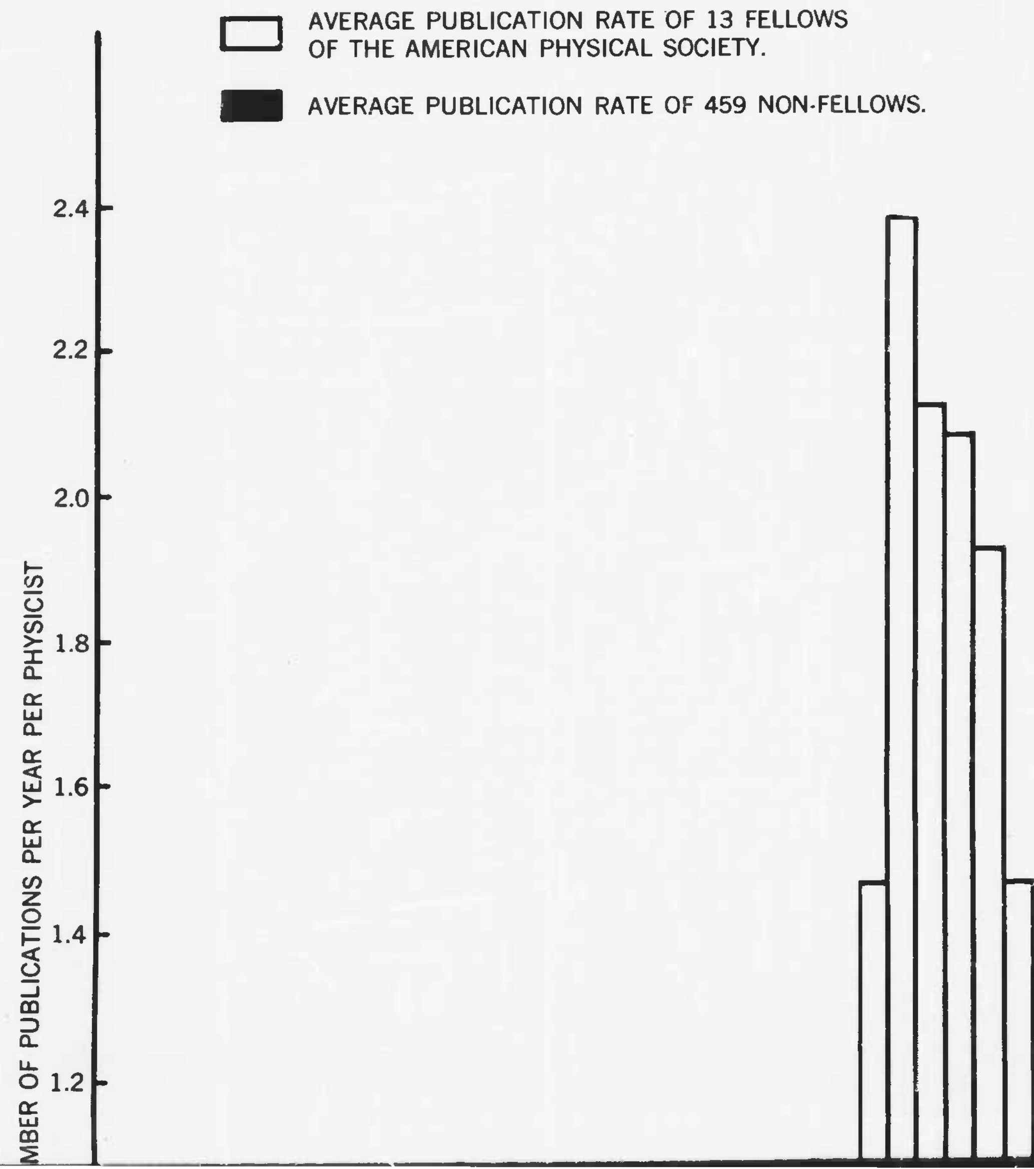
Figures C-13 through C-16 show the cumulative percent of publications in *The Physical Review* plotted against the cumulative percent of authors ranked in decreasing order of their rate of publication. Figure C-13, for example, refers to the graduating class of 1936. Of the 143 members of this class, 20% have contributed 80% of all the publications appearing in *The Physical Review* from 1920 to 1957.

Since many science students abandon basic research after completing their academic work, and all their scientific publications derive directly from their dissertation, we have also included graphs similar to the ones in Figures C-13 through C-16, but with papers published during the first three years following graduation subtracted. We now find that 10% of the 1936 graduating class accounts for 80% of all publications contributed by this class appearing in *The Physical Review* from 1939 to 1957 (Figures C-17 through C-20).

Chemists

The American Chemical Society publishes annually a *Directory of Graduate Research*, which lists publications and biographical information about faculty members in universities with graduate schools in chemistry, chemical engineering, and biochemistry. Figure C-21 shows the age distribution of chemistry faculty members as related to academic rank; Figure C-22 the percentage of all faculty members who published five or more scientific papers in the years 1954–1956, plotted against age.

Together, these graphs suggest that the rate of publication of chemists on university staffs is not seriously affected by age or attainment of tenure ranks. The apparently lower publication rate of younger men is explained by the fact that their scientific productivity does not span the full three-year period for which publications are reported.


AVERAGE PUBLICATION RATE OF 13 FELLOWS OF THE AMERICAN PHYSICAL SOCIETY.
AVERAGE PUBLICATION RATE OF 459 NON-FELLOWS.
2.4
2.2
2.0
1.8
1.6
1.4
1.2
MBER OF PUBLICATIONS PER YEAR PER PHYSICIST

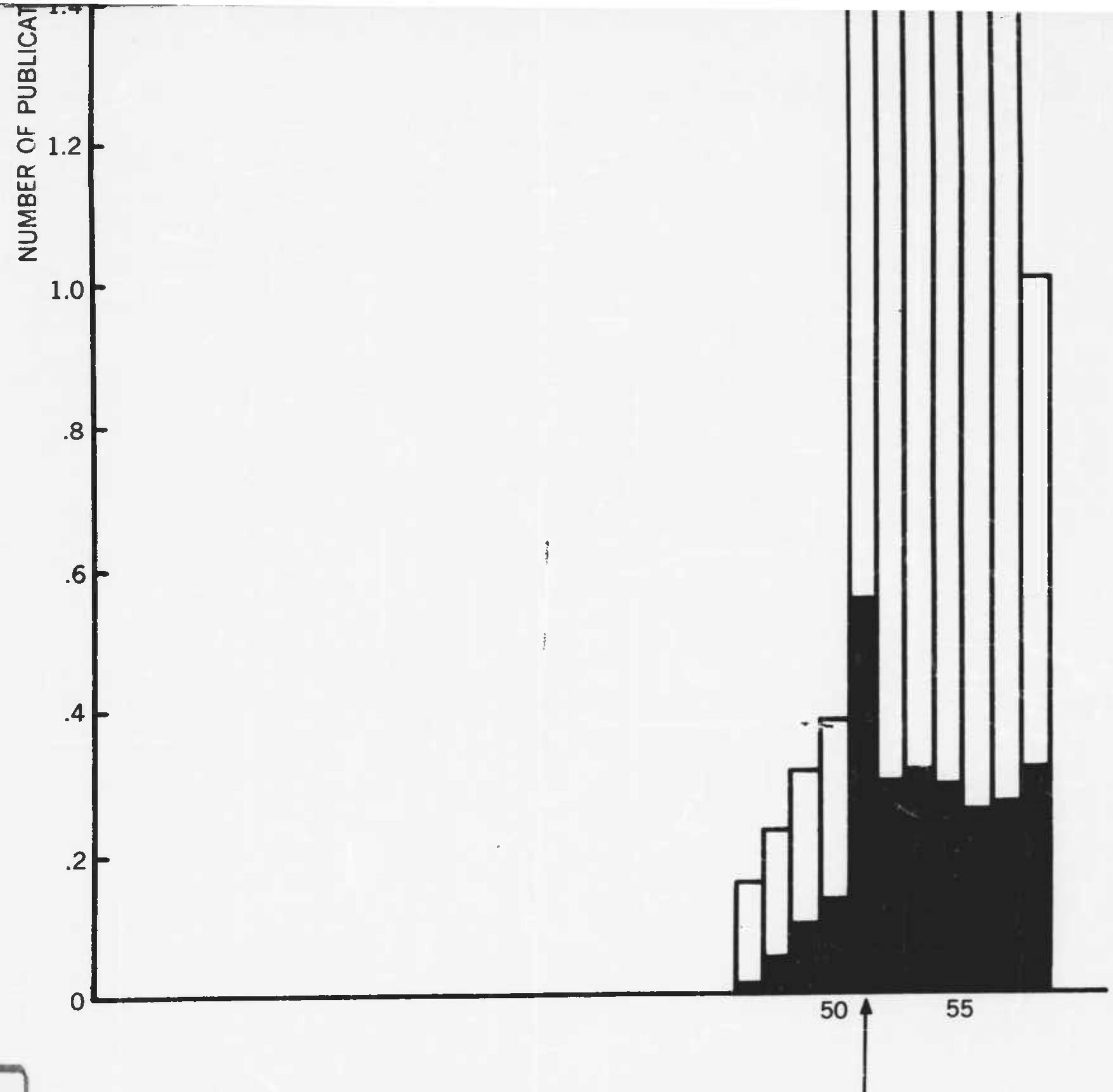
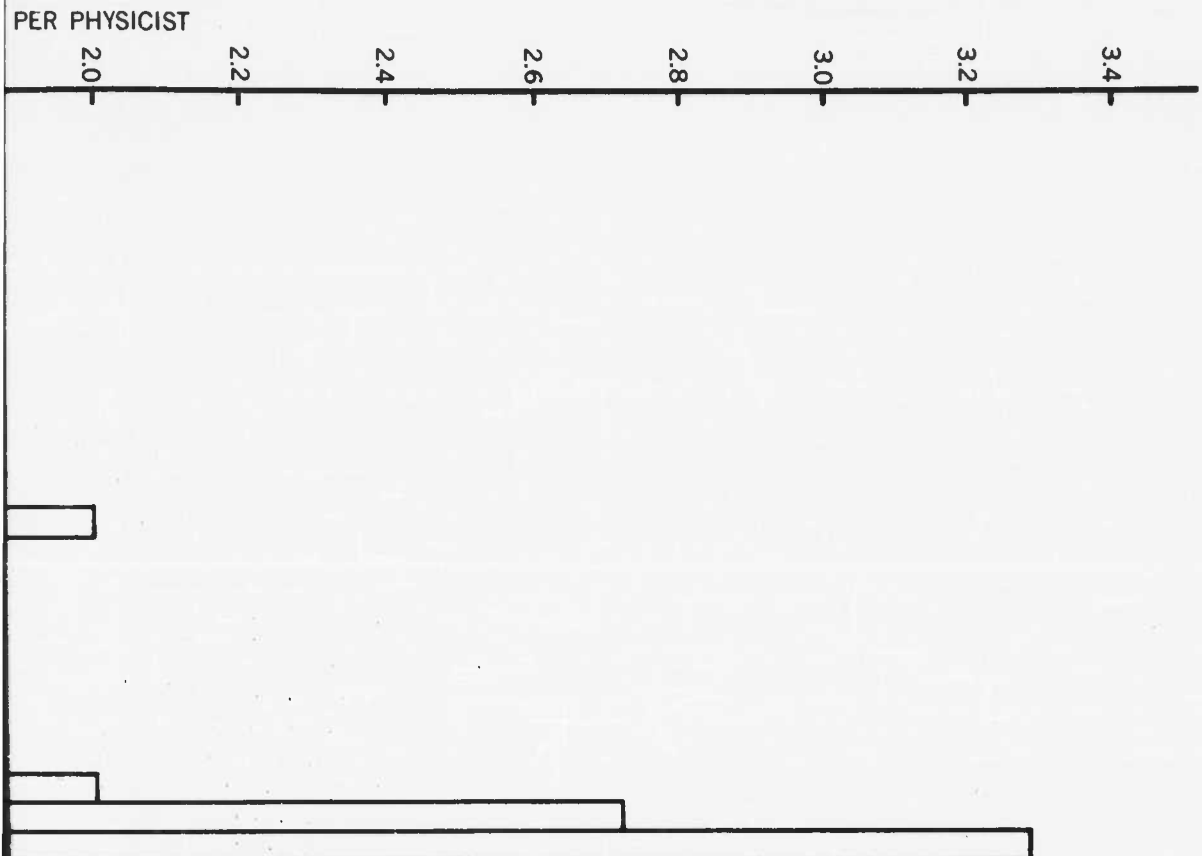


FIGURE C-11
PUBLICATION RATE IN *THE PHYSICAL REVIEW*
OF PHYSICISTS WHO OBTAINED Ph.D. IN 1951



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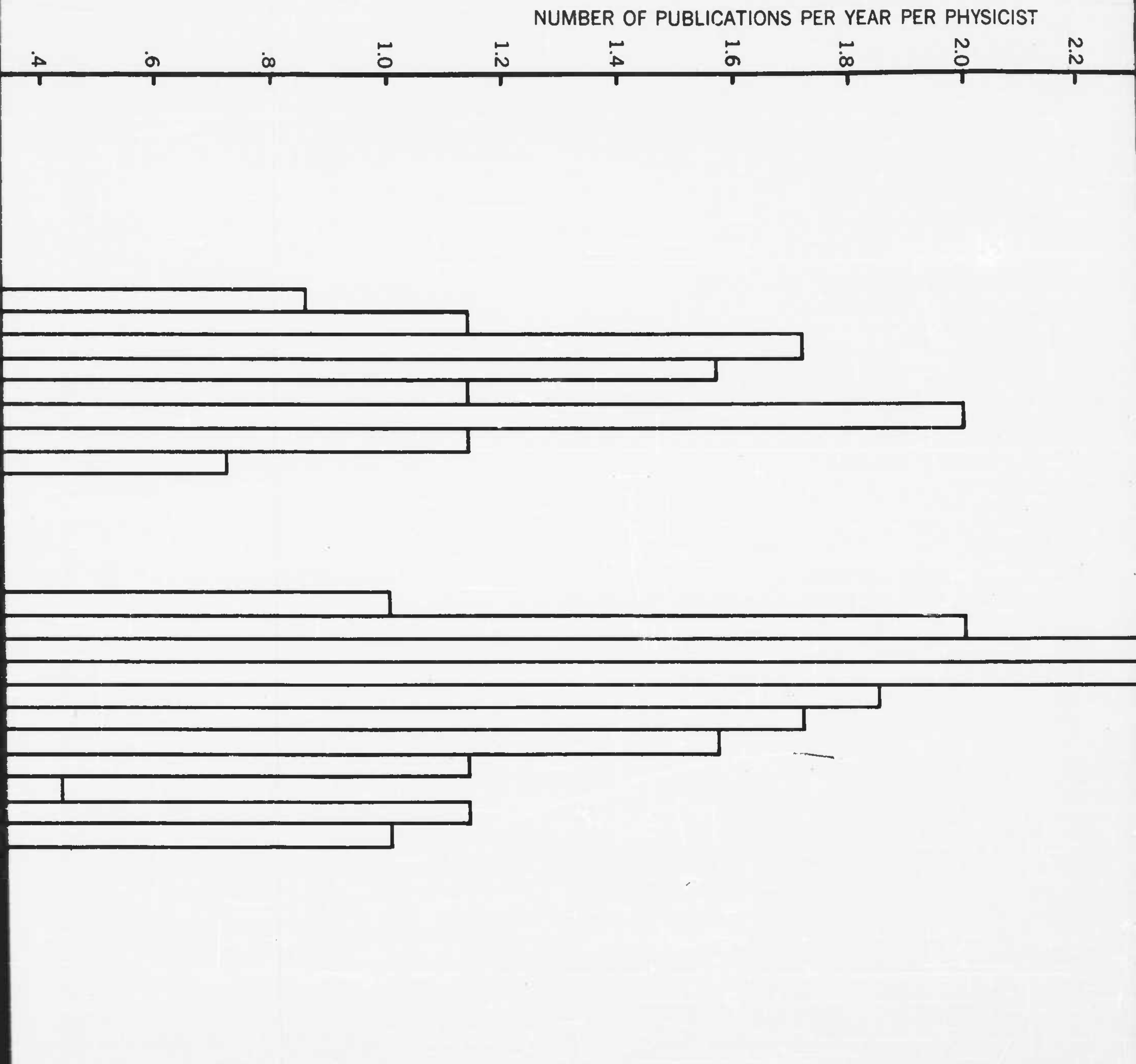
NUMBER OF PUBLICATIONS PER YEAR PER PHYSICIST
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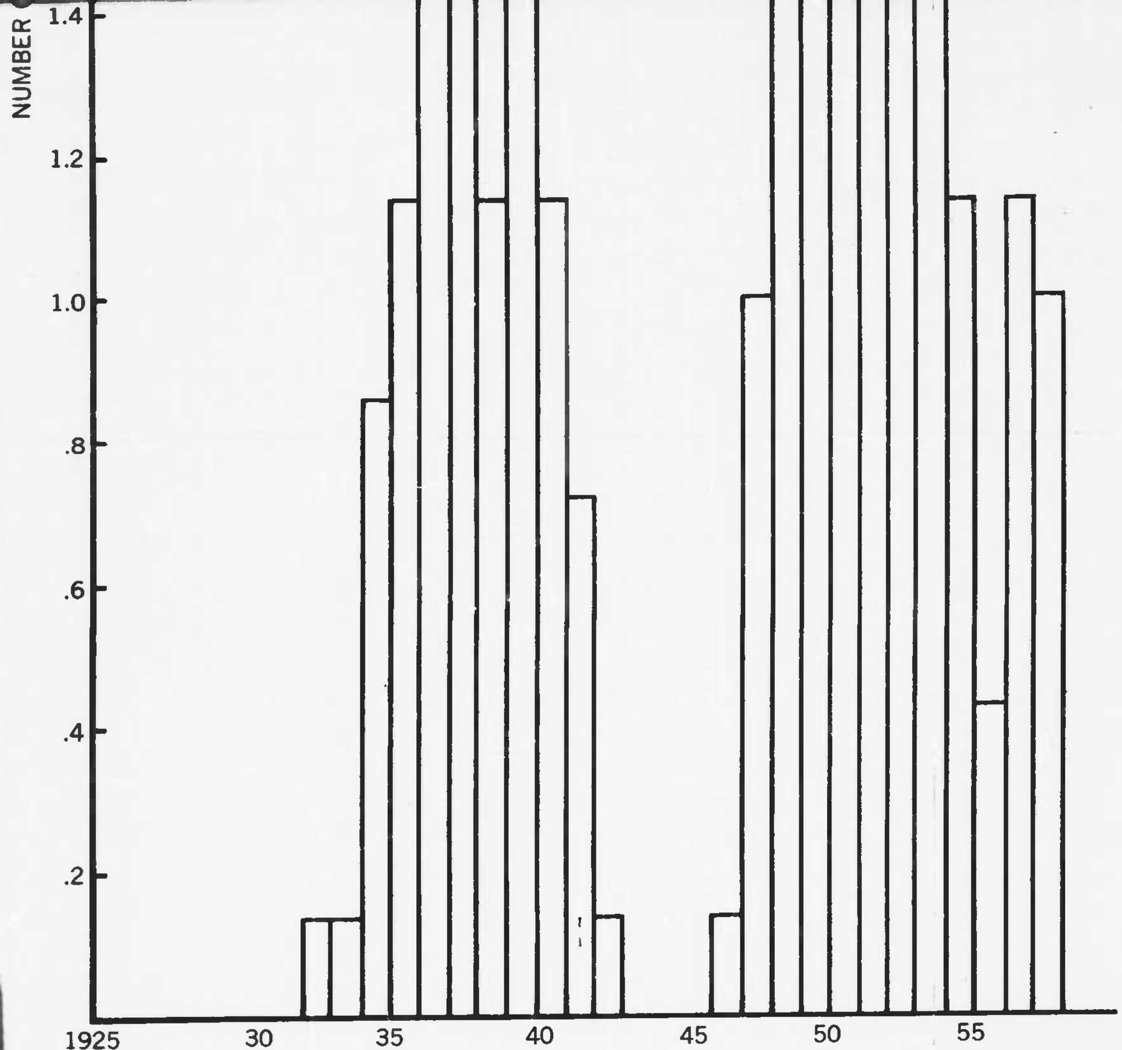

FIGURE C-12
PUBLICATION RATE OF 7 PHYSICISTS WHO OBTAINED Ph.D. IN 1936 AND ARE NOW MEMBERS OF THE NATIONAL ACADEMY OF SCIENCE

3

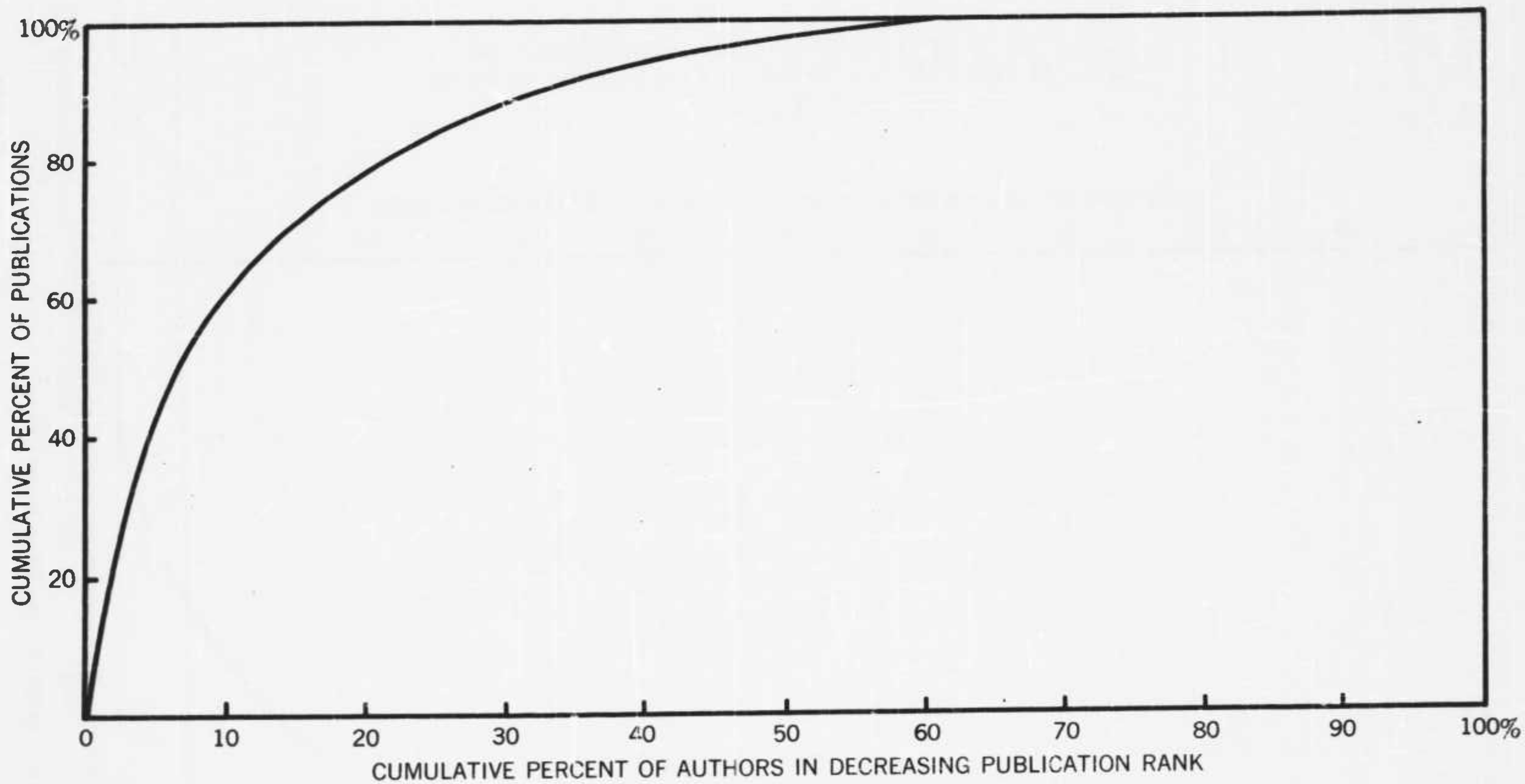

FIGURE C-13
PUBLICATIONS IN *THE PHYSICAL REVIEW* 1920-1957
BY PHYSICISTS WHO RECEIVED Ph.D. IN 1936

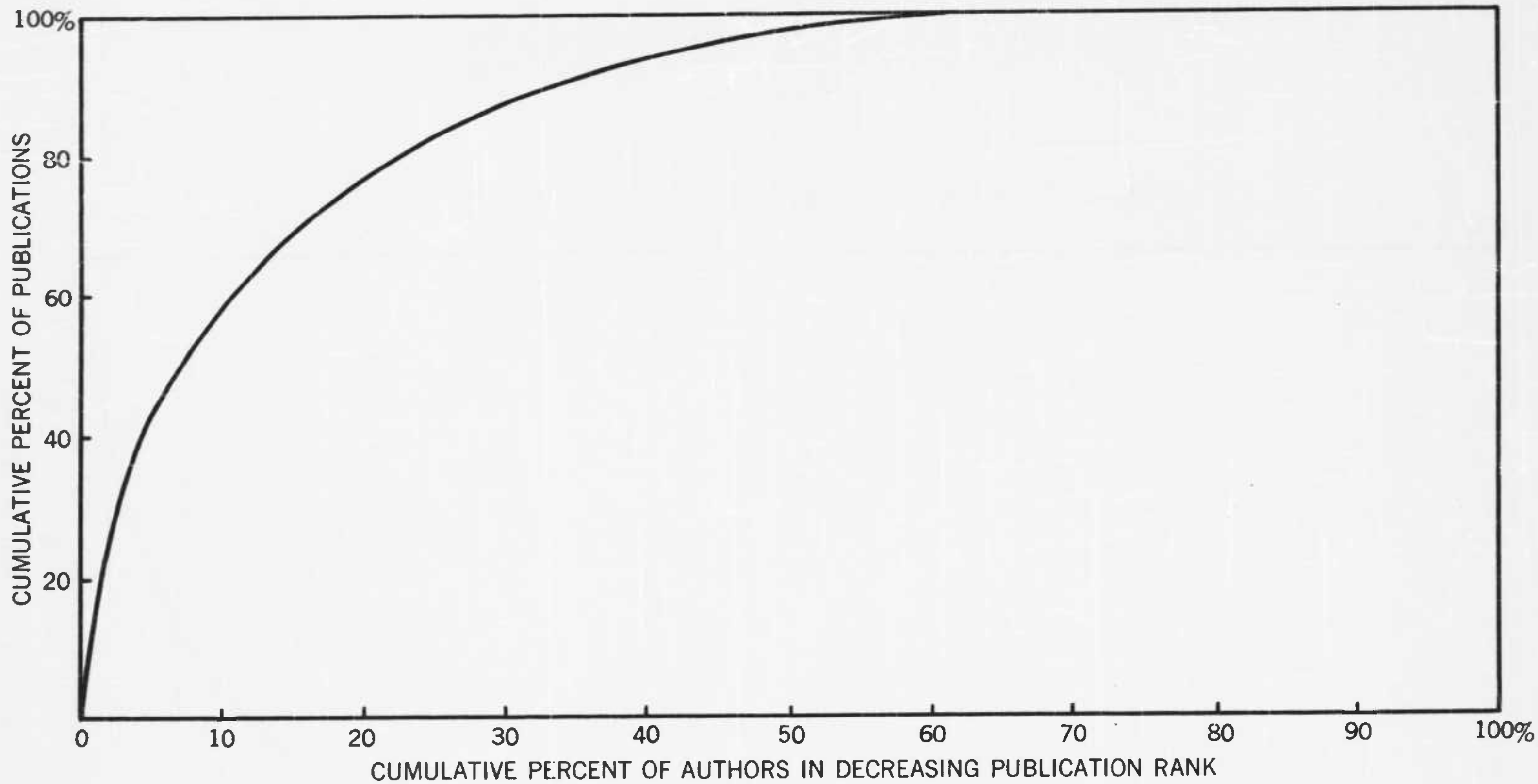

FIGURE C-14
PUBLICATIONS IN *THE PHYSICAL REVIEW* 1920-1957
BY PHYSICISTS WHO RECEIVED Ph.D. IN 1941

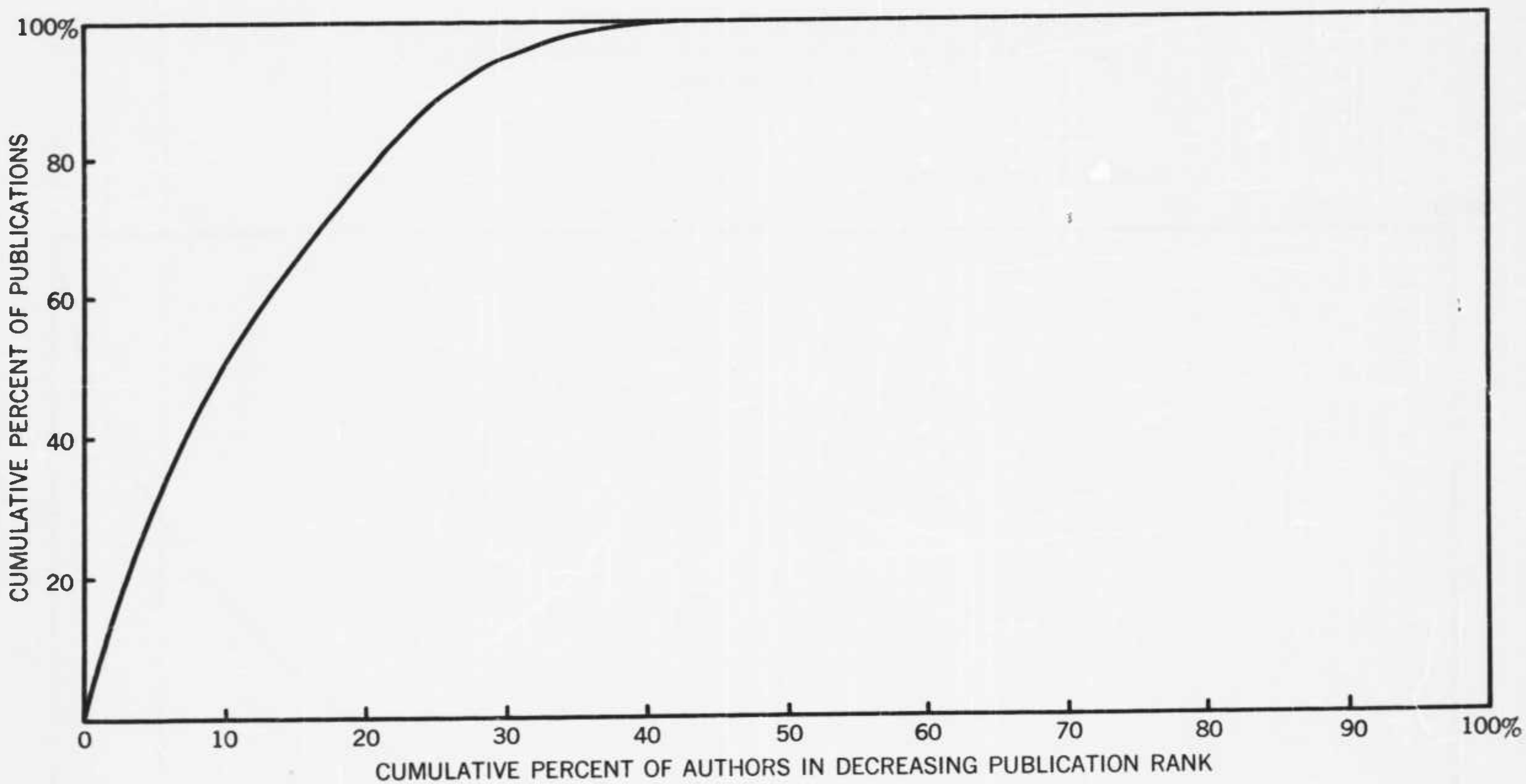

FIGURE C-15
PUBLICATIONS IN *THE PHYSICAL REVIEW* 1920-1957
BY PHYSICISTS WHO RECEIVED Ph.D. IN 1946

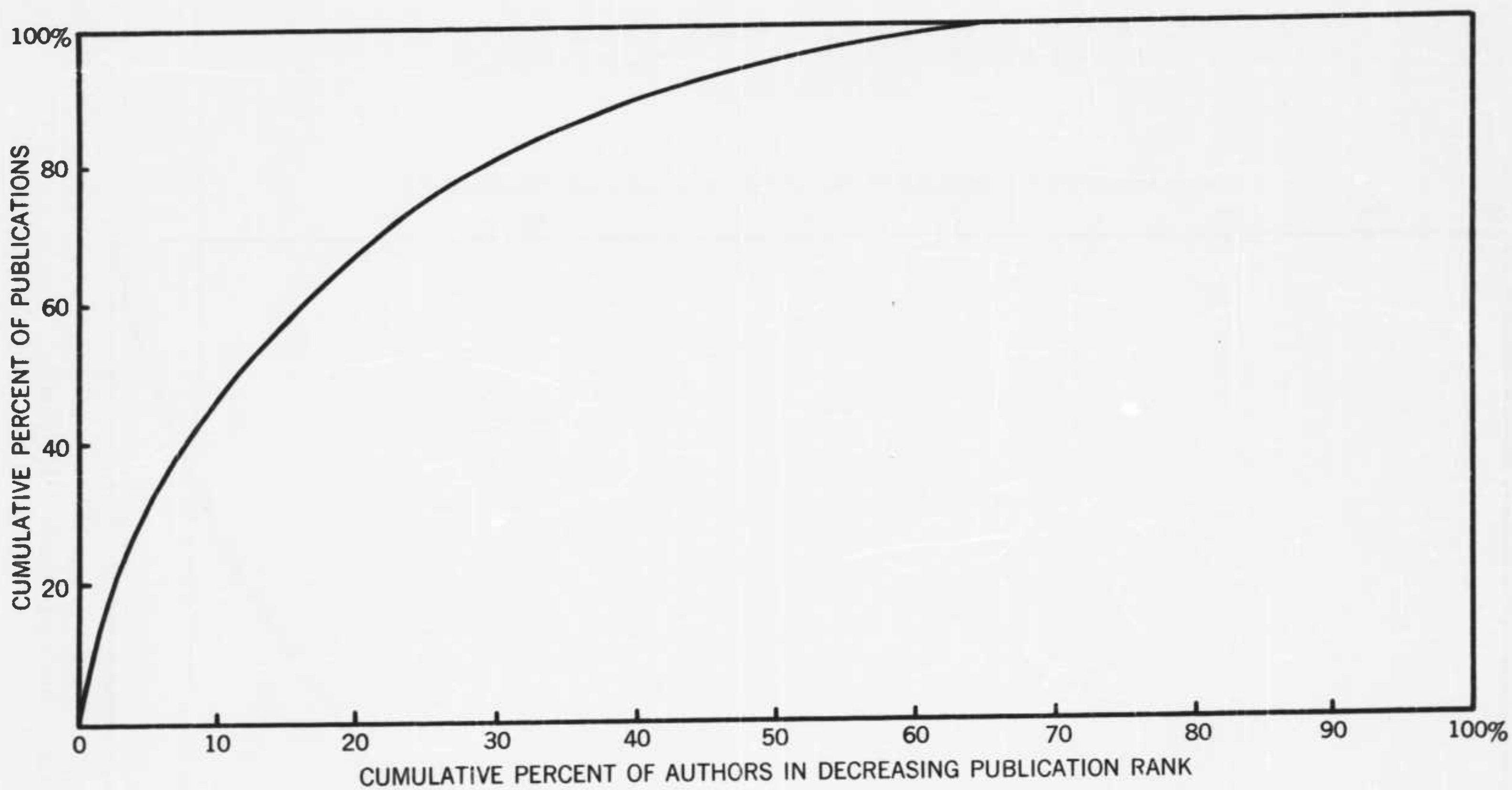

FIGURE C-16
PUBLICATIONS IN *THE PHYSICAL REVIEW* 1920-1957
BY PHYSICISTS WHO RECEIVED Ph.D. IN 1951

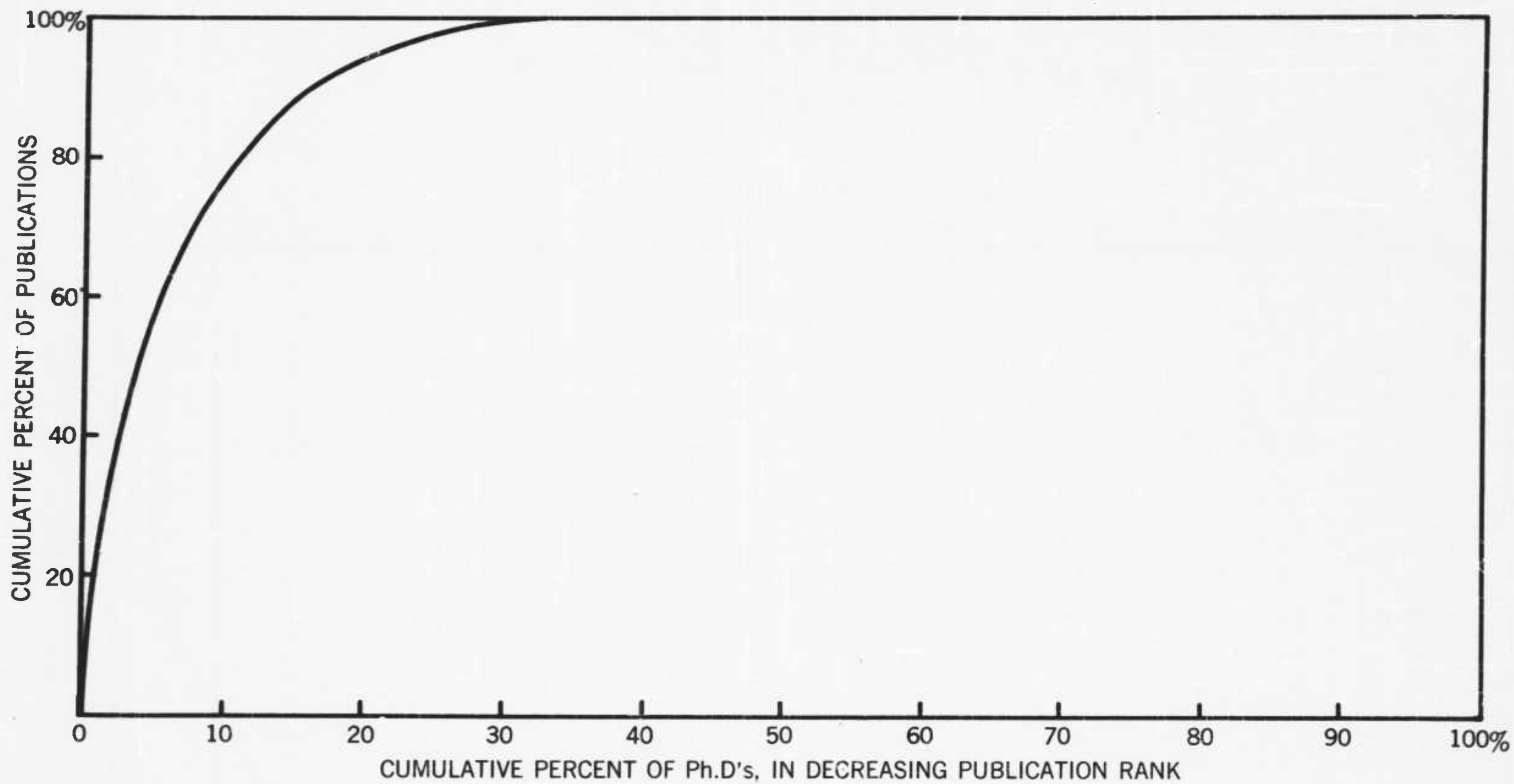

FIGURE C-17
PUBLICATIONS IN *THE PHYSICAL REVIEW* 1939-1957
BY PHYSICISTS WHO RECEIVED Ph.D. IN 1936
(first three years after degree removed)

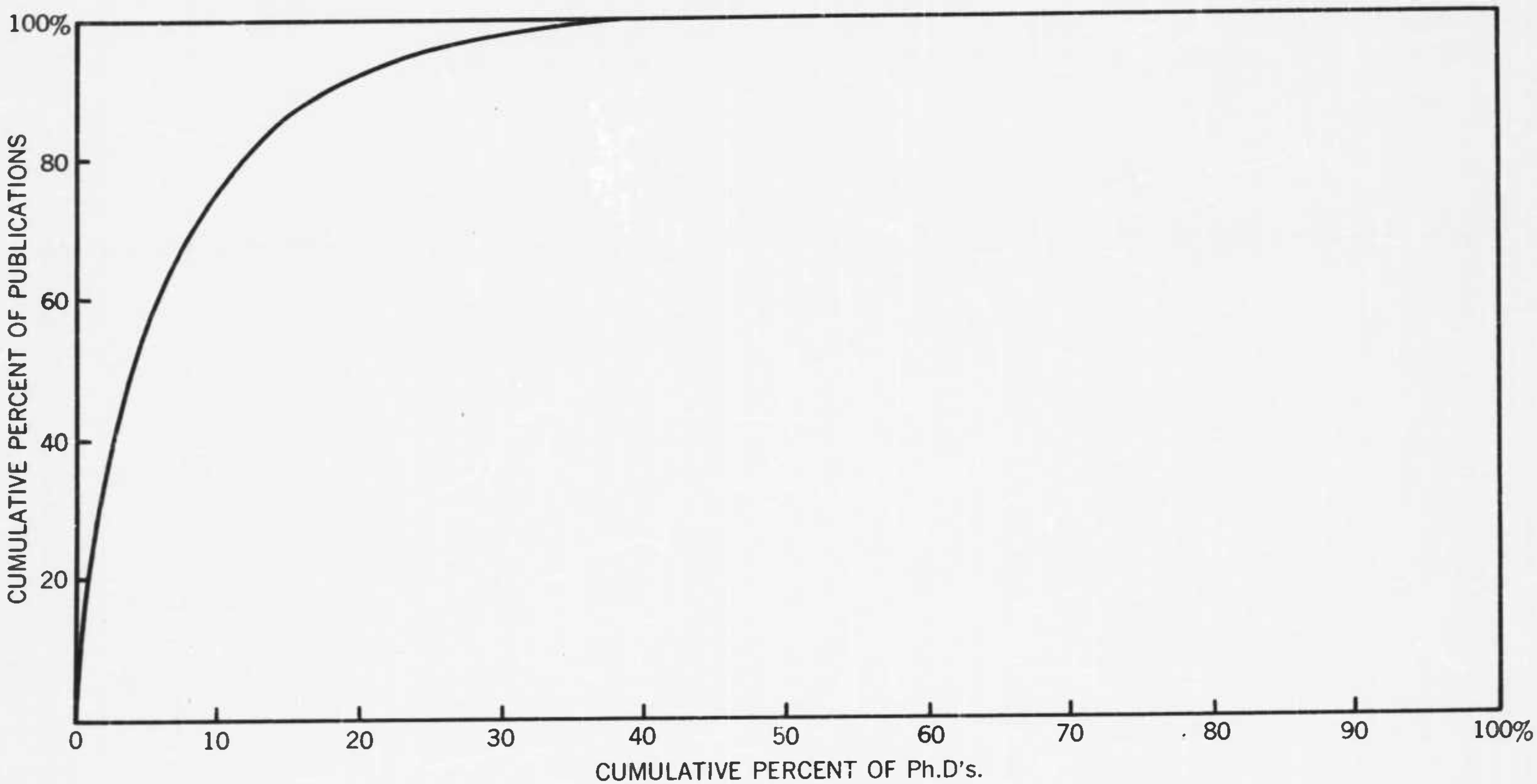

FIGURE C-18
PUBLICATIONS IN *THE PHYSICAL REVIEW*
BY 1941 Ph.D.'s – 1944-1957
(first three years after degree removed)

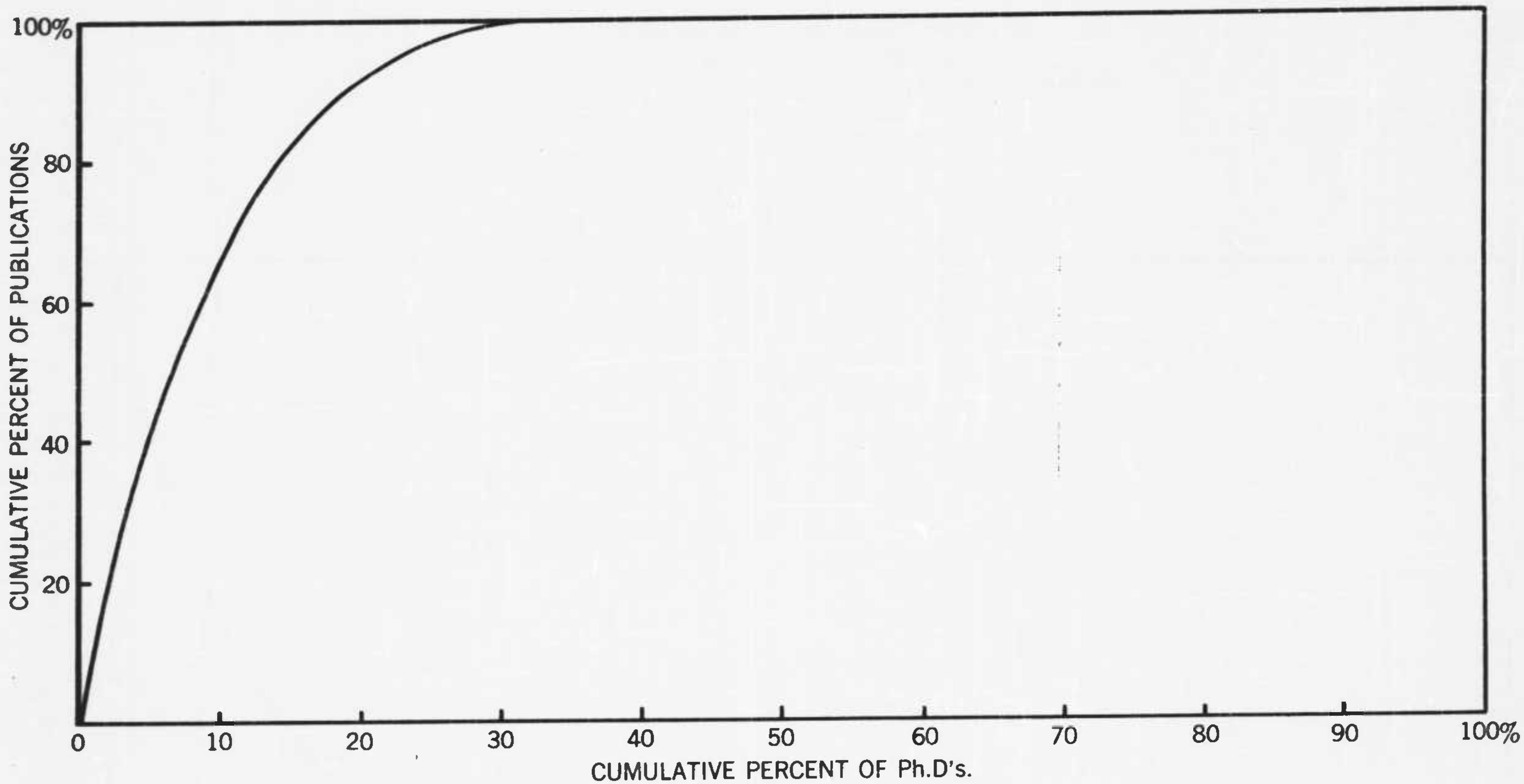

FIGURE C-19
PUBLICATIONS IN *THE PHYSICAL REVIEW*
BY 1946 Ph.D.'s – 1949 - 1957
(first three years after degree removed)

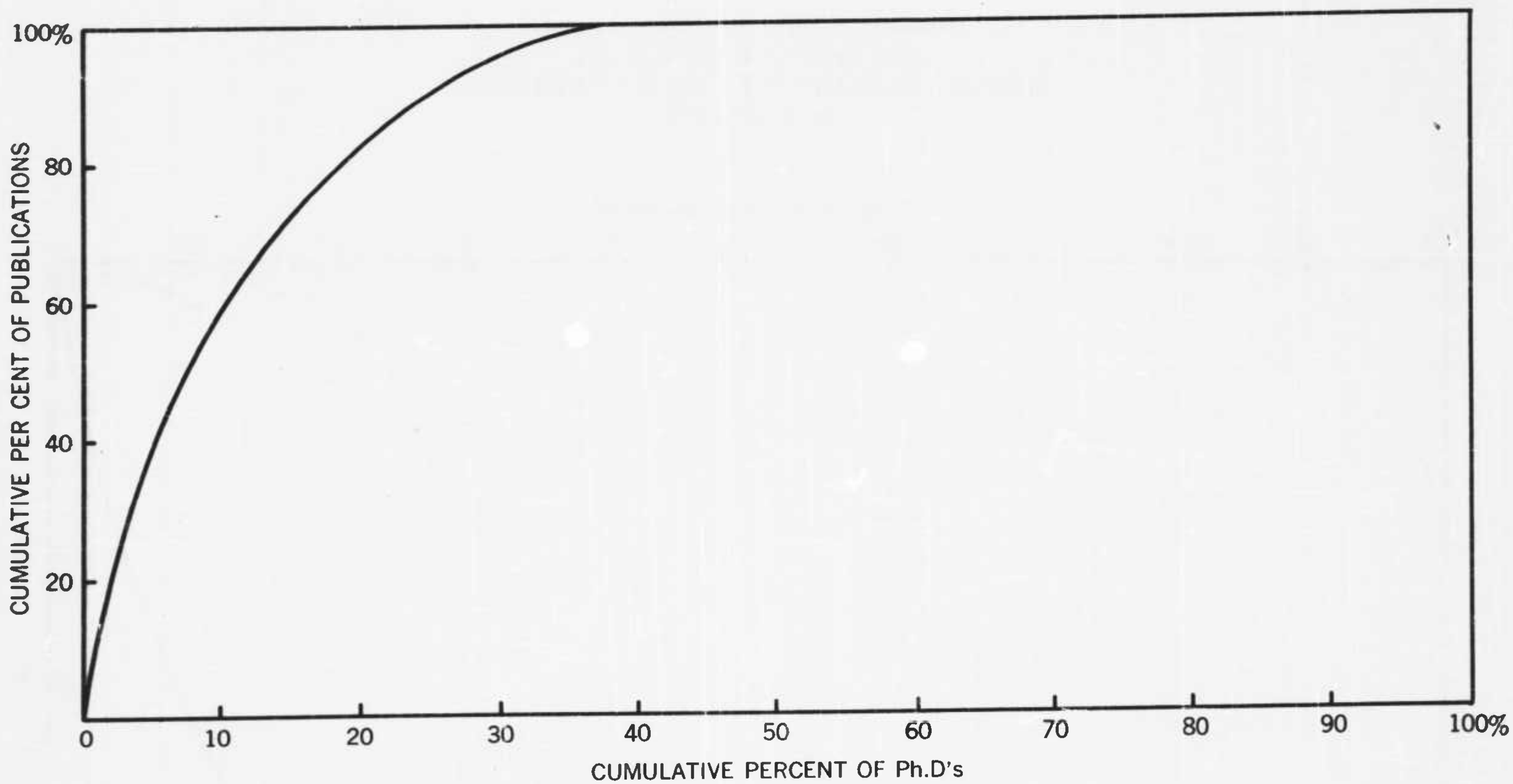

FIGURE C-20
PUBLICATIONS IN *THE PHYSICAL REVIEW*
BY 1951 Ph.D.'s – 1954 - 1957
(first three years after degree removed)

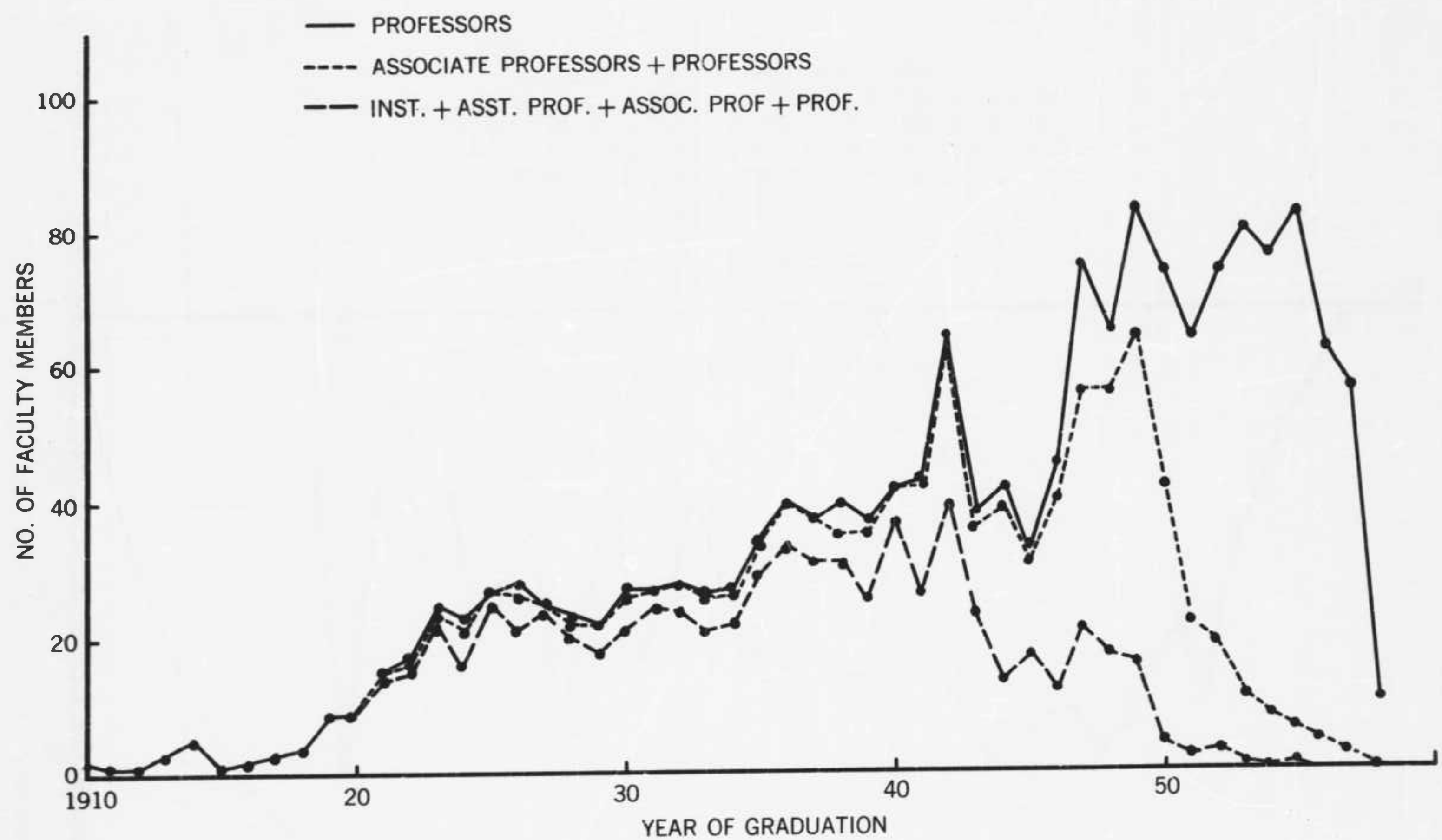

FIGURE C-21
UNIVERSITY FACULTY MEMBERS (CHEMISTRY DEPARTMENTS) YEAR OF CRADUATION (Ph.D.) AND PRESENT ACADEMIC RANK

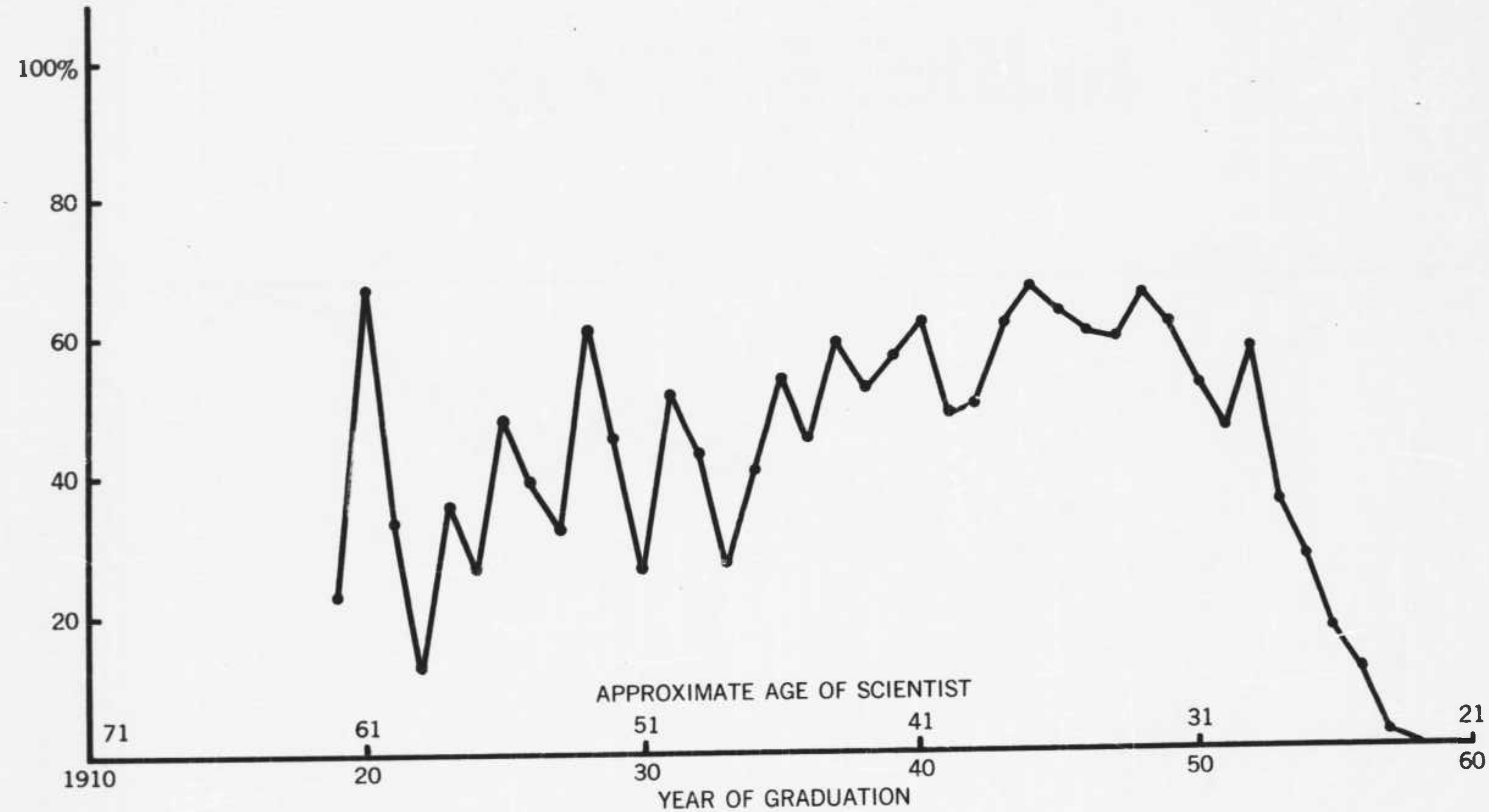

FIGURE C-22
PUBLICATION RATE AS FUNCTION OF AGE
UNIVERSITY FACULTY MEMBERS (CHEMISTRY DEPARTMENTS) PERCENT PUBLISHING 5 OR MORE PAPERS DURING THE PERIOD 1954-1956, BY YEAR OF GRADUATION (Ph.D.)

The total number of publications of chemists who received a doctorate in 1936 and 1941 was determined from the Author Index of *Chemical Abstracts*. Figures C-23 and C-24 show the average number of publications per chemist per year from 1927 to the present. The contribution of these two classes of chemists to the *Journal of the American Chemical Society* is presented in Figures C-25 and C-26. Approximately 30% of all Ph.D. chemists contribute 80% of the research publications appearing in the *Journal of the American Chemical Society*.

Basic Research — Expenditures, Personnel, Publications

Three measures of research effort have been considered:

- Basic research expenditures
- Number of scientists and engineers engaged in basic research
- Number of scientific publications generated by research institutes.

Table C-XII compares these three independent measures of basic research activity. Research expenditures are based on data assembled by the National Science Foundation (See Table C-I). Research publications refer to scientific papers in the thirteen scientific journals listed below.

Physical Review
Journal of Chemical Physics
Journal of Physical Chemistry
Journal of the American Chemical Society
The Journal of Organic Chemistry
Journal of Applied Physics
Journal of the Acoustical Society of America
Journal of the Electrochemical Society
Transactions of the American Society of Mechanical Engineers
Proceedings of the Institute of Radio Engineers
Review of Scientific Instruments
Annals of Mathematical Statistics
Transactions of the American Mathematical Society

(Biological sciences are not represented in this sample because journals in these fields are very numerous and highly specialized, and the analysis of only a few might lead to misleading results.)

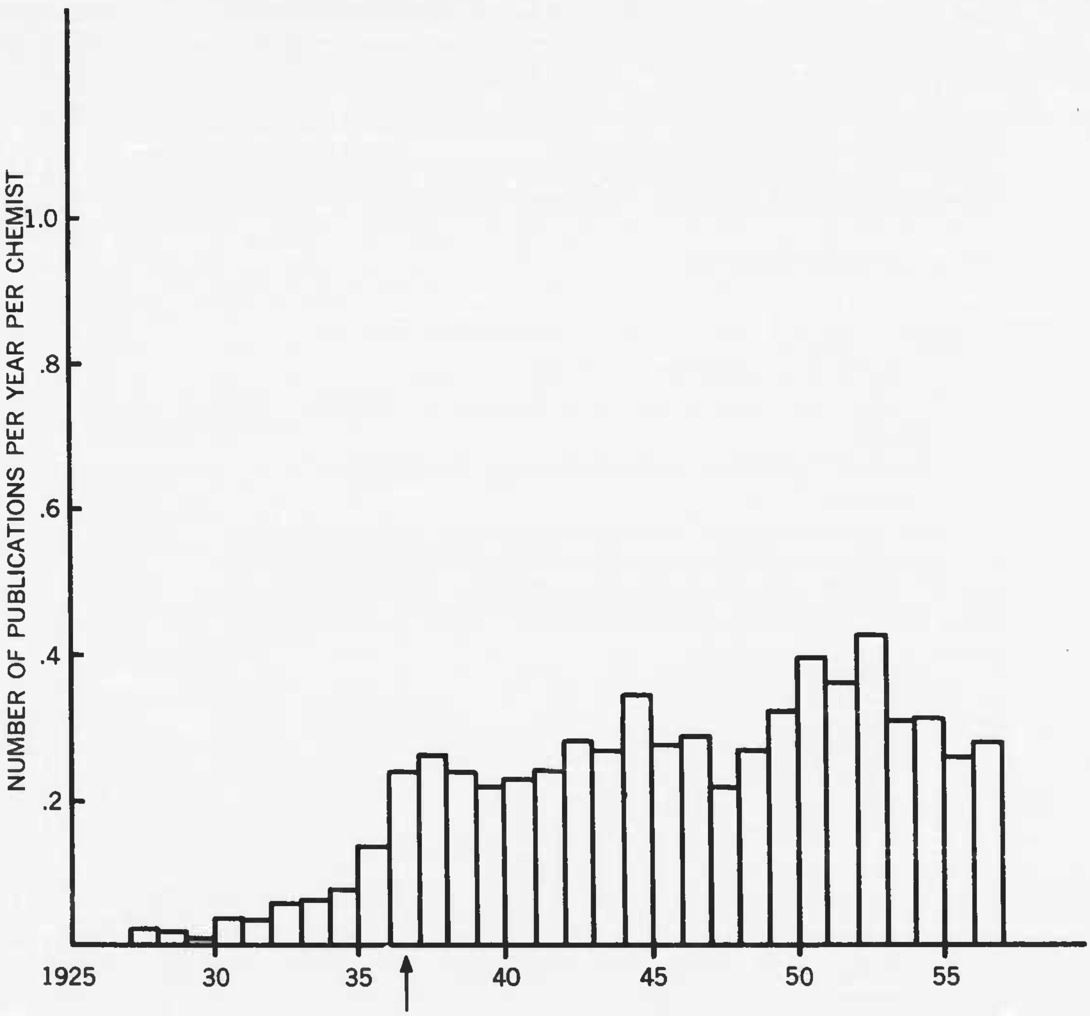

FIGURE C-23
PUBLICATION RATE OF CHEMISTS WHO OBTAINED Ph.D. IN 1936
(BASED ON ARTICLES SUMMARIZED IN *CHEMICAL ABSTRACTS*)

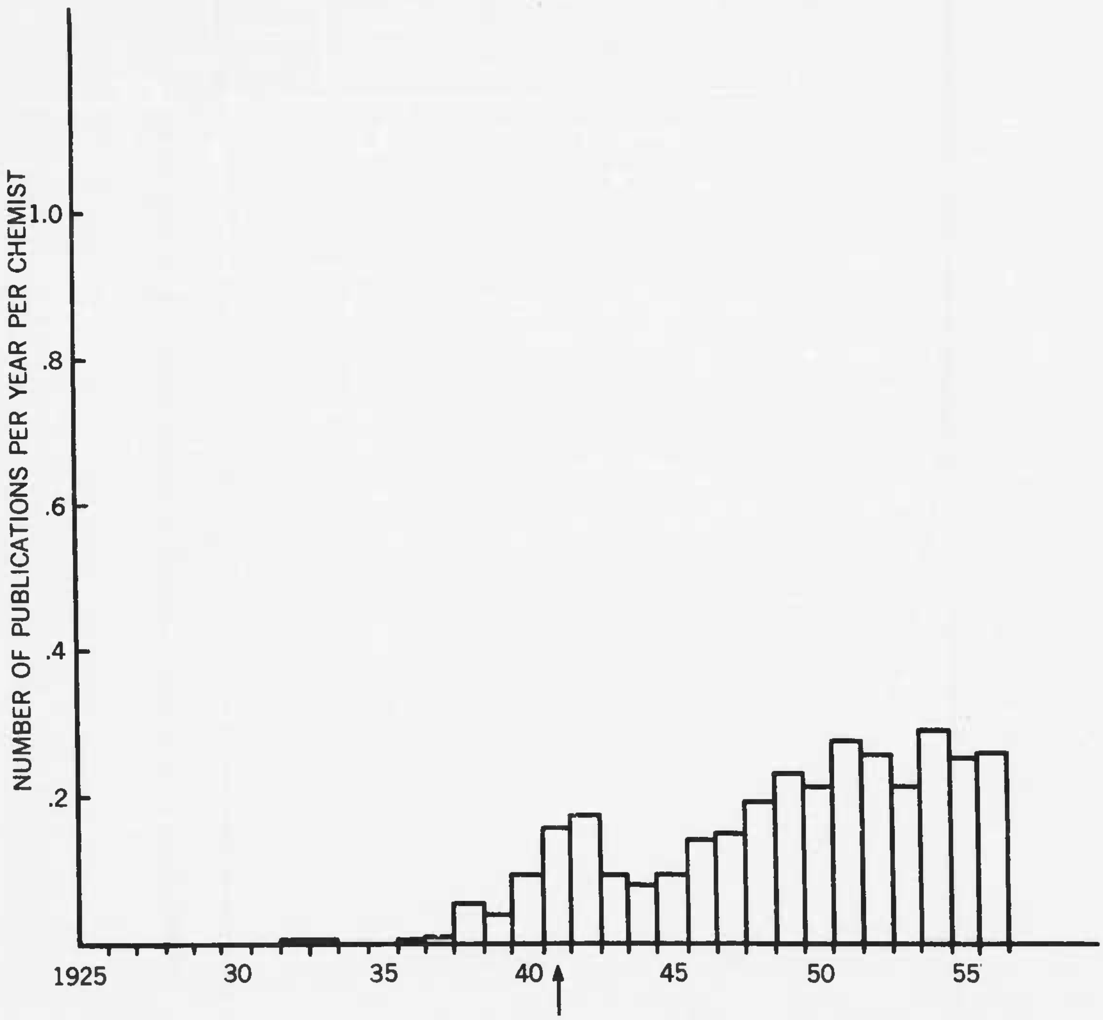

FIGURE C-24
PUBLICATION RATE OF CHEMISTS WHO OBTAINED Ph.D. IN 1941
(BASED ON ARTICLES SUMMARIZED IN *CHEMICAL ABSTRACTS*)

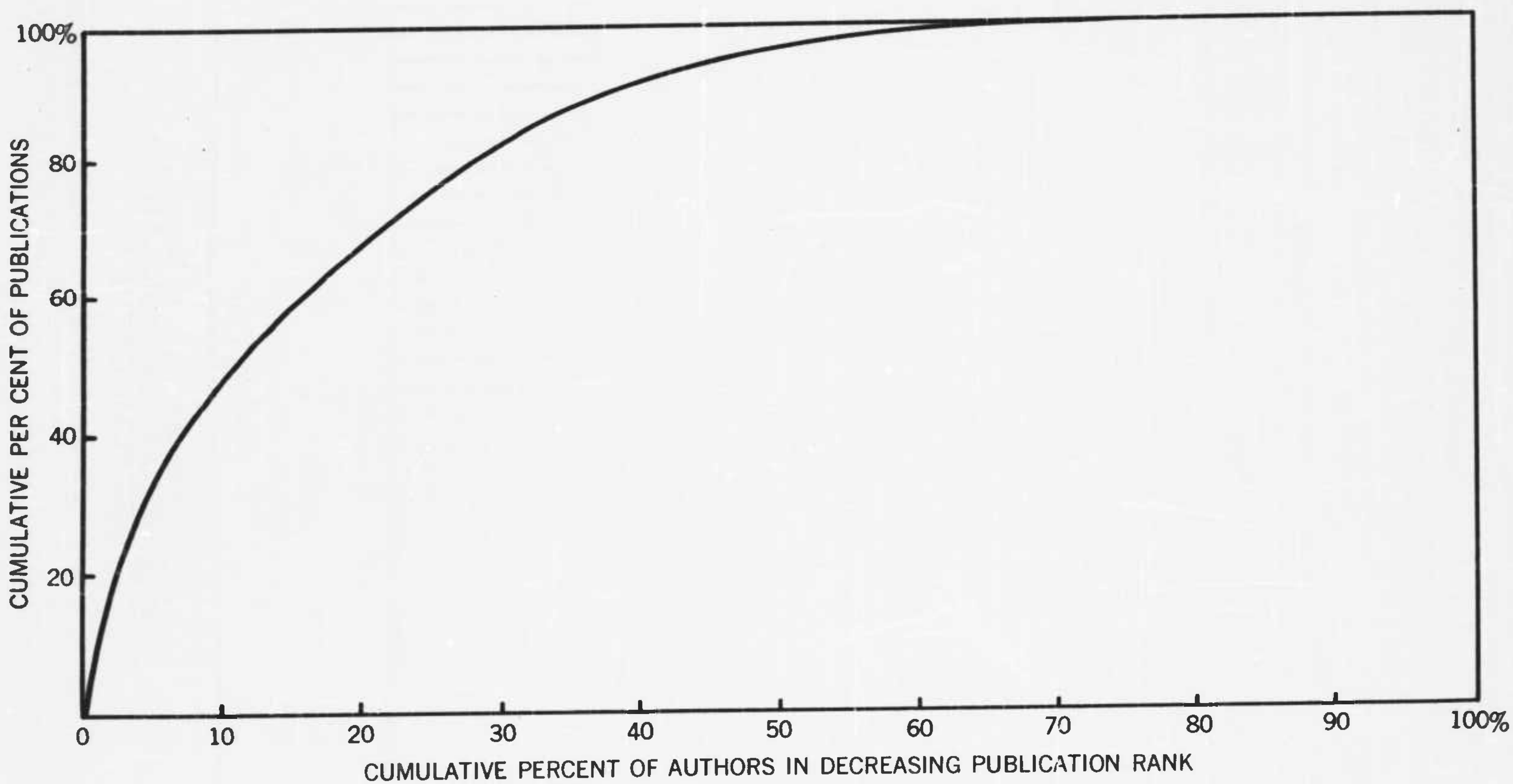

FIGURE C-25
PUBLICATIONS IN *THE JOURNAL OF AMERICAN CHEMICAL SOCIETY* 1927-1956 BY CHEMISTS WHO RECEIVED Ph.D. IN 1936

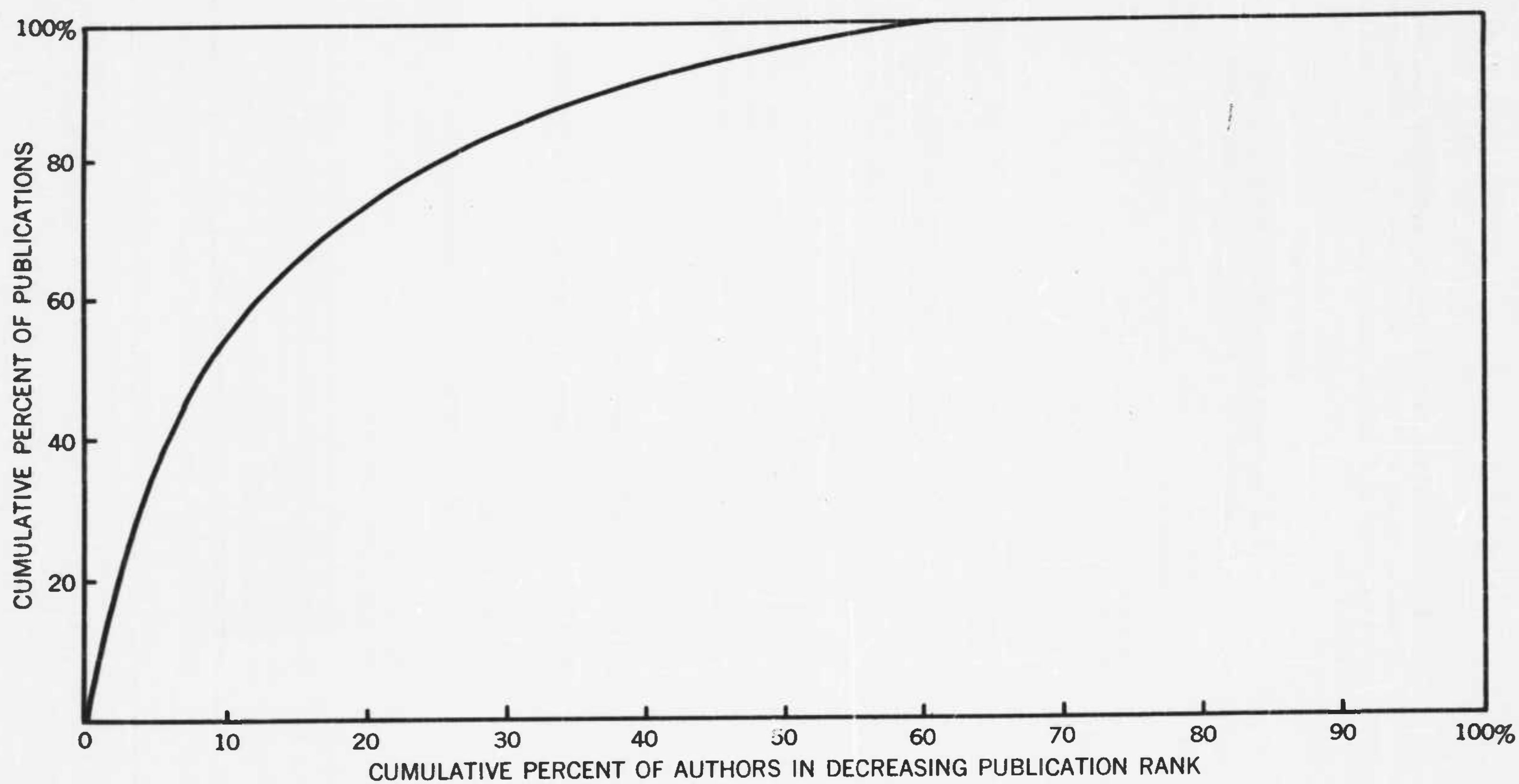

FIGURE C-26

PUBLICATIONS IN *THE JOURNAL OF AMERICAN CHEMICAL SOCIETY* 1939-1956 BY CHEMISTS WHO RECEIVED Ph.D. IN 1936

The number of scientists and engineers engaged in basic research is derived on the assumption that expenditures per man in basic research are comparable with those in research and development activities (See Table C-V).

TABLE C-XII

Basic Research Expenditures, Manpower, and Publications by Type of Research Organization

Type of Organization	Basic Research Expenditure	Publication Rate	Number of Researchers
Government	11%	9%	7%
Industry	39	19	27
Educational and Non-Profit Institutions and Other	50	72	66

Expenditures refer to the fiscal year 1953, whereas publications refer to 1957. This time differential is justified by the following considerations:

1. There is always a considerable delay between the time when research is performed and when results appear in print
2. During the period 1953–1957 no major shifts occurred in research activities or in publication policies.

Government, industry, and educational institutions are all actively engaged in basic research. The three measures of basic research effort employed in the analysis lead to comparable results, with Government laboratories accounting for 10% of the total, industry for 30%, and universities and other non-profit institutions 60%.

Basic Research Requirements and Support

Industry Practice

One approach to the problem of determining the level of basic research effort required by the Department of Defense is to consider industry practices, particularly in fields of rapid technical development and high product obsolescence.

4.5% of industrial R & D expenditures is for basic research

Basic research accounts for approximately 4.5% of all research and development expenditures in industrial laboratories. This figure cannot be directly compared with Government practices because industrial research is centered in relatively few very large companies.

Fourteen chemical, electrical, pharmaceutical, and petroleum companies individually questioned in the course of this study allocate on the

average 12.5% of their research and development budget to basic research. Table C-XIII lists the research expenditures of these companies in the years 1947 and 1957. During this period research and development expenditures increased by a factor of 3, and basic research by a factor of 4.5.

In 1957, three companies accounted for 60% of all industry publications in *The Physical Review* (See Table C-XIV).

TABLE C-XIII

Research Expenditures of Sample Companies

Type of Industry	Number of Companies in Sample	1947 Total R & D	1947 Basic Research	1957 Total R & D	1957 Basic Research
Petroleum	4	$ 49 M	$6 M	$180 M	$30 M
Chemical	4	61	7	174	24
Pharmaceutical	3	5	.5	16	2
Electrical	3	148	8	402	44

physics research concentrated in relatively few large industrial laboratories

In 1937 the same three companies accounted for 90%, and in 1949 for 70% of all physics research of a fundamental nature. Thus we see that concentration of physics research in relatively few large laboratories is not a recent development.

A similar picture emerges from a review of thirteen leading scientific and technical journals. Ten companies in the electrical, chemical, and petroleum industry, with 12% of the research and development personnel employed in industry, are responsible for 40% of all industry publications.

In 1957 the combined output of basic research in physics of the three armed services was lower than the output of two industrial corporations: Bell Laboratories and the General Electric Company. The total number of research publications in the physical sciences originating in Government laboratories, both military and non-military, was matched by the output of fifteen leading industrial firms.

TABLE XIV

The Physical Review

Publications Originating in Industrial Laboratories

	1937	1949	1957
Bell Laboratories	3	14	42
General Electric	7	8	27
Westinghouse	2	6	26
RCA	0	3	12
IBM	0	0	5
Other	1	11	42
Industry Total	13	42	154

the Department of Defense, more than any other group, benefits directly from the unpredictable contributions of basic research

On the basis of this evidence, one finds that to achieve the ratio of basic research to research and development expenditures of the larger companies in the electrical, chemical, and pharmaceutical industries, the Department of Defense should increase basic research budgets by approximately 150%. Even greater support of basic research can be justified in view of the magnitude of defense needs and the size of military establishments compared with the size of private corporations. Only organizations with great financial resources, long-range objectives, and very diversified activities can profitably invest in basic research. The Department of Defense, more than any other group, benefits directly from the unpredictable contributions of basic research.

Government-Sponsored Research

In 1956 the research and development budget of the Department of Defense was $1925 million. The Navy Department component was $462 million or 24%. A fraction of these expenditures was allocated to Government laboratories operated by the military services.

Table C-XV shows the number of technical papers contributed to sixteen leading scientific journals by these laboratories in 1956 and 1957. Navy laboratories accounted for two-thirds of the total.

TABLE C-XV
Department of Defense Research Publications
1956–1957

Journal	Number of Publications* Navy	Air Force	Army
Proceedings of the Institute of Radio Engineers	16	6	15
Journal of Applied Mechanics	7	2	3
Journal of Applied Physics	32	3	9
Journal of Chemical Physics	29	15	14
The Physical Review	79	4	7
Journal of American Chemical Society	47	3	26
American Institute of Electrical Engineers	18	2	1
Journal of Optical Society of America	28	10	17
Journal of Physical Chemistry	33	0	5
Journal of the Electrochemical Society	17	1	0
Astrophysics	5	2	0
American Society of Mechanical Engineers	7	2	2
Journal of the Acoustical Society of America	39	18	1
American Society for Testing Materials	2	0	2
Journal of Metals	5	2	5
Industrial and Engineering Chemistry	16	2	10
Total	380	72	117

* Data prepared by Dr. Peter King of the Naval Research Laboratories.

In addition to research performed in Government laboratories, the military services and other Government agencies sponsor research in industry and educational institutions. It is accepted practice for the authors of scientific papers reporting on work supported by Government agencies or private institutions to acknowledge receipt of this support.

We have reviewed the 1957 volumes of *The Physical Review* and of the *Journal of The American Chemical Society* to identify the contribution of the Department of Defense and of the Atomic Energy Commission to research publications in these two journals. Results are summarized in Table C-XVI.

TABLE C-XVI

Research Sponsored by the Department of Defense and the Atomic Energy Commission

Sponsoring Agency	Number of Articles
The Physical Review	
Army	84
Navy	295
Air Force	145
AEC	521
Journal of the American Chemical Society	
Army	76
Navy	79
Air Force	47
AEC	108

Fifty-four percent of the articles published in *The Physical Review* in 1957 reporting on research performed in the United States in non-Government laboratories acknowledge financial assistance from the Department of Defense or the Atomic Energy Commission. Over 90% of this work was performed in educational and other non-profit institutions.

Twelve percent of the articles published in the *Journal of the American Chemical Society* in 1957 reporting on research performed in the United States in non-Government laboratories acknowledge financial assistance from the Department of Defense or the Atomic Energy Commission. Over 95% of this work was performed in educational and other non-profit institutions.

a large potential for research growth exists in academic and industrial laboratories

One way of increasing the national basic research effort is for the Government to expand its role of financial sponsor of meritorious projects. Several studies have indicated that a large potential for research growth exists in academic and industrial laboratories.

Table C-XVII was prepared by the Coordinating Committee on Science of the Department of Defense. It shows the total number and dollar value of meritorious proposals rejected by the Department of Defense in the fiscal year 1957, and the budget for the fiscal year 1958 in each field. Only a small fraction (about 6%) are duplicates. If every proposal classified as meritorious by the Department of Defense were accepted, the contract research program of the Department of Defense would be increased 70%.

The National Science Foundation has reported the data in Table C-XVIII about proposals rejected due to lack of funds. The NSF was able to grant only 28% of the funds requested for meritorious proposals.

TABLE C-XVII

Meritorious Research Proposals Rejected in Fiscal 1957

Departments of the Army, Navy, and Air Force

	No. of Proposals	Amount	FY 58 Budget Ests. (Basic Research)
Astronomy and Astrophysics	1	$ 9,200	$ 774,000
Biology	16	153,490	3,608,000
Cartography and Geodesy	2	7,375	245,000
Chemistry	101	2,613,282	6,348,000
Combustion	29	1,287,935	2,871,000
Earth Physics	9	142,000	306,000
Geography	7	740,369	824,000
Mathematics	73	1,747,891	4,118,000
Mechanics	90	3,434,648	7,872,000
Medical Sciences	95	1,172,196	9,011,000
Meteorology	9	354,000	1,184,000
Oceanography	22	2,003,700	2,000,000
Physics	302	29,654,499 (16,654,499)**	24,398,000
Psychology	48	1,348,441	1,895,000
Sociology	—	—	156,000
Total	804*	$44,669,026* ($31,669,026)**	$65,610,000

* Duplicate Proposals Included, 50, $2,877,199.

**Total if the $13,000,000 item for a 15-45 Bev Linear Electron Accelerator at Stanford University is eliminated.

TABLE C-XVIII

Meritorious Proposals Received and Grants Awarded 1953–1957
National Science Foundation
(Millions of Dollars)

Fiscal Year	Total Funds Requested	Total Funds Awarded	Meritorious Proposals Not Supported
1953	$ 8.0	$ 1.7	$ 6.3
1954	17.9	3.9	14.0
1955	25.8	7.8	18.0
1956	37.5	9.9	27.6
1957	51.0	15.5	35.5
Total	$140.2	$38.8	$101.4

These data would indicate that there is a drastic shortage of funds to support meritorious research proposals. There are some points to be considered in looking at these estimates:

there is a drastic shortage of funds to support meritorious research proposals

> If funds were increased, requests would also increase. This effect can be seen very clearly in the National Science Foundation data.
>
> The proposals classified as meritorious are rated on the basis of the personal judgment of scientific referees.
>
> If all the meritorious proposals which are submitted to Government agencies were supported, a number of research organizations might find themselves seriously understaffed.

Most research projects cannot be viewed in isolation. An effective research team is assembled slowly over a period of years and cannot contract or expand to respond to changes in the availability of financial resources. The average life of all active contracts in the Contract Research Program of the Office of Naval Research is five years and two months. Out of a total of 871 projects now actively supported, 251 have been continuous since 1950. We note, however, that 92% of the research agreements between the Office of Naval Research and university and industrial laboratories are due to expire by 1960. Contracts of longer duration would probably prove beneficial both to the Navy and to scientific progress.

Appendix D

Chronology of Naval Technical Developments

this list of events has been prepared to illustrate the impact of science and technology in the evolution of the U. S. Navy

This list of events has been prepared to illustrate the impact of science and technology in the evolution of the U. S. Navy. A great many suggestions of items to be included have been received from the various technical agencies within the Navy, and their interest and help are gratefully acknowledged. The authors, however, take full responsibility for the many arbitrary decisions that have necessarily been made regarding those to be listed.

The objective has been to develop a chronology of reasonable length confined to advances in science and technology originating within or first adopted practically by the Navy. It begins with the foundation of our Republic. It does not include items relating to the navies of other countries, and in general the dates of adoption of such foreign innovations by the U. S. Navy are not included unless there is some unusual reason for so doing, such as situations that reflect conditions peculiar to the United States. Similarly, developments made by other branches of the U. S. Armed Forces have been omitted unless their integration into Navy materiel or operations presented special problems.

Serious effort was made to maintain a suitable balance of emphasis among the various disciplines and technologies. Where U. S. Naval officers are mentioned, their rank at the date of the item has been used.

Time did not permit an exhaustive confirmation of the items, and obviously it was necessary to rely on information received from Navy technical specialists regarding the importance and details of many of those listed. There are naturally opportunities for disagreement with our judgment about the importance or background of the individual developments, but we hope that the chronology will be looked at as a whole, rather than in detail, from the point of view of the increasingly rapid pace at which new scientific discoveries and technological developments are being incorporated into equipment and operations by the Navy.

1777	**Mine** invented by David Bushnell killed three of the crew of the British frigate "Cerberus" at New London when hauled aboard.
	Submarine for military purposes built by David Bushnell, Saybrook, Conn., could support one operator for 30 minutes without a new supply of air.
1787	**First Marine Hospital** founded by the Commonwealth of Virginia at Norfolk to serve the Navy and Merchant Marine.
1789	**Experiments on ships and guns** by Navy authorized by First Congress.
1797	**Frigates** (United States, Constellation, Constitution) launched, more heavily gunned and faster than frigates in any other Navy.
1800	**Submarine** Nautilus built by Robert Fulton while living in Paris.
1801	**Marine Hospital** purchased by the Federal Government as the first U. S. Marine Hospital. It was formerly the Marine Hospital of the Commonwealth of Virginia.
1802	**The New American Practical Navigator** published by Nathaniel Bowditch, adopted by U. S. Navy as standard authority on navigation.
1804	**Catamaran torpedo** invented by Robert Fulton used by British fleet.
1807	**Steamboat** "Clermont" put in operation by Robert Fulton and R. R. Livingston.
1808	**"Observations on the Means of Preserving the Health of Soldiers and Sailors** and on the Duties of the Medical Department of the Army and Navy, with Remarks on Hospitals and Their Internal Arrangement," believed to be the earliest scientific book by a naval officer, published by Naval Surgeon Edward Cutbush.
1810	**Marine specimens** (shell-fish, etc.) brought from ocean bottom for examination by device invented by Cdr. Stephen Decatur.
1811	**Naval hospital** established by act of Congress.
1814	**Steam-propelled warship,** built by Robert Fulton at a cost of $320,000, launched at Brown's Shipyard, New York, as the "Demologos" or "Fulton the First."
1821	**School for midshipmen** established on board the "Guerierre" in New York City.
1830	**Naval Depot of Charts and Instruments** founded; progenitor of Naval Observatory and Hydrographic Office; observation work in astronomy, magnetism, and meteorology started; 30-inch transit was first astronomical instrument for the Navy.
	U. S. Naval Time Service established.

United States Naval Lyceum formed at the New York Navy Yard under leadership of Capt. M. C. Perry, "to promote the diffusion of useful knowledge."	1833
Mathematical measurement of the base line on Long Island, New York, the first in the United States ever measured scientifically, with participation of Passed Midshipman John A. Dahlgren.	1834
Screw propeller invented by John Ericsson.	
New Theoretical and Practical Treatise on Navigation published by Lt. Matthew Fontaine Maury.	1836
Antarctic continent charted on four-year exploration by Lt. Charles Wilkes.	1838
Warship with below-waterline propelling machinery, "Princeton," first screw warship ever built. "Mississippi" commissioned, the U. S. Navy's first ocean-going steam warship.	1841
Naval Observatory began operation.	1844
Naval Academy established at Annapolis (transferred to Newport 1861, returned to Annapolis 1865).	1845
"Wind and Current Charts of the North Atlantic" compiled and published by Lt. Matthew Fontaine Maury.	1847
Experimental naval ordnance firing range established on the Anacostia River by Lt. John A. Dahlgren.	1848
Nautical Almanac Office founded at Cambridge, Mass.; compilation of America's ephemeris begun with Lt. Charles H. Davis as first superintendent of the Office.	1849
"Bottle-shaped" Dahlgren gun, America's first scientifically designed gun.	1850
Measurement of ocean depth by explosive sound attempted by Lt. Matthew Fontaine Maury.	
Naval Medical Laboratory founded at Brooklyn, N. Y.	1853
Mines used by the Confederate Navy.	1861
Rifled cannon first tried on a mass basis in the Civil War, and to a limited degree breechloaders also.	
Water distilling apparatus improvised on board "Mississippi" to obviate leaving blockade station in order to take on fresh water.	
Hospital ship, "Red Rover," used by the Navy.	1862
Iron vessel with turrets, "Monitor," launched at Greenpoint, N. Y.; designed and built by John Ericsson; the revolving turret with which it was equipped was invented by T. R. Timby.	
Liquid compasses improved by E. S. Ritchie and (1866) W. R. Hammerslag	

1862	**Monitor-Merrimack (CSS Virginia)** clash in Hampton Roads, Va.; first battle between ironclads foreshadows the end of wooden warships
1863	**National Academy of Science** formed on the initiation of the Navy's Permanent Commission.
1864	**Submarine sinking of enemy ship;** Confederate "David" built by H. L. Hunley sank Federal "Housatonic."
	Transmission of standard time via telegraph, Navy and Western Union.
1866	**Hydrographic Office** established by Congress.
	Steam-driven steering gear introduced; first use of steam to power auxiliary shipboard equipment.
1869	**Torpedo station** established in Newport Harbor.
1873	**U. S. Naval Institute** founded to advance professional, literary, and scientific knowledge in the Navy; Adm. D. D. Porter was first president.
1875	**Steam power** to generate electric power first used aboard ship.
1876	**Torpedo boat,** "Lightning," 58 feet long with a speed of 20 mph, built at Bristol, R. I., by J. B. and N. G. Herreshoff.
1878	**Measurement of velocity of light** by Albert A. Michelson, on equipment constructed himself, while an instructor at the Naval Academy.
1881	**High-powered rifled guns** of "hooped" or "built-up" steel introduced.
1882	**Steel of domestic manufacture** stipulated by legislation for the first ships of the new Navy; this provision gave impetus to American steel industry.
1883	**Ship completely equipped for electric lighting:** "Trenton."
1884	**Naval War College** established.
1886	**Smokeless powder investigations** began at Naval Torpedo Station, Newport, by Charles E. Munroe; reached successful development by 1891.
1887	**Armor-Plate** contract awarded to Bethlehem Iron Company for 6000 tons for the battleships "Maine" and "Texas" and four monitors.
1888	**Effect of hollowed charges** demonstrated by C. E. Munroe at Naval Torpedo Station; applied to bazooka in World War II.
	Experiments with wireless telegraphy on board ship (some years before Marconi's success), by Lt. Bradley Fiske.
1890	**Armored battleship,** "Maine," carrying side armor 12 inches thick, launched.

Smokeless powder grain perforation developed; it is in general use throughout the world today.	
Hospital ship, "Solace," fitted out in 1898 and used in the war with Spain.	1898
Naval Model Basin opened at the Navy Yard, Washington, D. C.	1899
Astronomical time reference originated by S. Newcomb.	1900
First submarine in U. S. Navy, "Holland," is commissioned.	
Marconi wireless devices installed in three U. S. Naval ships; radio stations erected at Washington, D. C., and the Naval Academy at Annapolis, Md., to test various methods and types of radio equipment.	
Smokeless powder plant built at Indian Head to manufacture powders developed at Newport.	
Torpedo-Boat Destroyer, "Bainbridge," displacing 420 tons, launched; progenitor of the modern destroyer.	1901
Continuous-aim tracking for guns introduced by Adm. Sims.	1902
Flight of an airplane with three-dimensional controls by Wright Brothers.	1903
Naval Experiment Station and Testing Laboratory authorized by Congress as a result of efforts of RAdm. George W. Melville.	
Naval Radio Station established at the Highlands of Navesink, N. J.	
Broadcasting of time by radio originated at the U. S. Naval Radio Station, Navesink, N. J.	1904
"Hot running" torpedo, using burning alcohol to increase air pressure, invented by F. M. Leavitt; the "cold running" torpedo powered by compressed air was perfected about 1868 by British engineer Robert Whitehead.	
Responsibility for a major portion of Government's use of radio assigned to Navy by President Theodore Roosevelt; at year's end, Navy had 33 ships and 18 shore stations equipped with radio.	
Bulbous bow warship, "Delaware," built on design of D. W. Taylor, Naval Model Basin, to reduce ship resistance.	1907
U. S. Navy established as world power as a result of its "Around-The-World-Cruise."	
Radiotelephone use on board naval ship achieved.	1908
Surveillance test for smokeless powder stored on ships introduced by G. W. Patterson of the Naval Powder Factory.	
U. S. Navy Radio Laboratory, predecessor of the Naval Research Laboratory, is established.	

1909 **Annual physical examination** of all officers instituted to determine fitness for duty.

Gyro-compass invented by Elmer Sperry tested on board "Birmingham."

High-power transmitter, a Fessenden 100-KW synchronous rotary spark apparatus contracted for installation at Arlington, Va. This radio station was commissioned in 1913.

1910 **Airplane flight from a ship** made by Eugene Ely, a civilian pilot of the Curtiss Co., from deck of cruiser "Birmingham"; it flew two miles to Willoughby Spit, Va.

"Speed and Power of Ships" published by RAdm. D. W. Taylor, presenting the standard series method of estimating ship resistance.

1911 **Airplane flying school** opened by the Curtiss Exhibition Co.; gave military officers free instruction in flying at the flying field at North Island, San Diego, Calif.

Diesel-powered submarines "Skipjack" and "Sturgeon" launched.

First airplane landing in the world on ship, "Pennsylvania," in San Francisco Bay.

First Navy airplane ordered, Curtiss Triad Amphibian.

Radio installed in naval aircraft for the first time.

1912 **Airplane catapulted** at the Washington Navy Yard, Washington, D. C., from catapult built under the direction of Capt. W. I. Chambers assisted by Naval Constructor H. C. Richardson, launched by Lt. T. G. Ellyson.

Large ship with electrical transmission of power, "Jupiter," built at Navy Yard, Mare Island, Calif., as a collier; it was converted to a carrier in 1922, named "Langley."

Submarine with radio signaling equipment received and transmitted signals off Newport, R. I., at a range of four miles.

Worldwide radio broadcasting of time originated at Naval Radio Station, Arlington, Va.

1913 **Aeronautical Engineering Course** established at Massachusetts Institute of Technology by Lt. Jerome C. Hunsaker.

Continuous radio contact with U. S. mainland maintained during transatlantic voyage, cruiser "Salem."

Photographs taken under sea by J. E. Williamson at Chesapeake Bay by use of Williamson submarine Tube and Photosphere.

1914 **Armor-piercing shell** introduced on wholesale basis.

Iceberg detected by underwater echo ranging, using a form of moving-coil transducer designed by R. A. Fessenden.

World's largest wind tunnel added to facilities of the Naval Model Basin to carry out experimental work in connection with the air resistance of naval vessels and the design of aircraft.

Radio-telephone message transmitted from Naval Wireless Station at Arlington, Va., to Mare Island, Calif. 1915

Aviation and submarine medicine began to be studied. 1917

Radio-controlled aircraft experiments begun.

Radiophone fog-warning device, the forerunner of the radio beacon, installed at Point Judith, R. I.

Air control radio system established (4-course radio ranges) to furnish guidance to aircraft. 1918

Anti-submarine mine barrage laid in the North Sea.

Flight refueling demonstrated by Lt. G. L. Cabot.

High-power, long-wave radio station NSS commissioned at Annapolis, Md., with 350 KW arc equipment.

Mines of the antenna type, firing electrolytically, mass produced.

Most powerful radio transmitting station in the world, 200 KW alternator, installed, New Brunswick, N. J. Navy ships in all parts of the world hear NFF as did field receivers at the front in France. This station flashed President Woodrow Wilson's "Fourteen Points" to Nauen, Germany.

Railroad mounted guns, 14"/50, operated in France and contributed to German decision to cease shelling Paris.

Submerged submarine received and sent radio signals; reception found possible from overseas stations in submarine whose periscope was 21 feet below the surface.

World's first automatic fire control anti-aircraft director and computer system installed to control 5"/25 gun mounts.

First transatlantic flight made by Navy's NC-4; Lt. Cmdr. A. C. Read was in command. 1919

Measures for safety of minesweepers employed in the sweeping of antenna mines during the clean-up of the North Sea mine barrage.

Radio voice communications transmitted from air to ground.

Feasibility of radio homing by aircraft on vessels at sea demonstrated by Naval Aircraft Radio Laboratory by homing of an F5L naval seaplane to "Ohio." 1920

Radio Lafayette, near Bordeaux, France, world's first 1000-KW long-wave radio station, commissioned.

Seaplane obtained accurate bearings by radio compass from a battleship off the Virginia coast.

1921 **Non-rigid U. S. Navy dirigible filled with helium gas,** replacing use of hydrogen, operated at Naval Air Station, Hampton Roads, Va.; first practical use of helium gas.

1922 **First Navy all-welded ship,** a fleet tug, was launched at Norfolk Naval Shipyard. This may have been the world's first all-welded ship.

First radio broadcast by a President of the United States carried out by the Naval Aircraft Radio Laboratory utilizing naval radio stations NSF and NAA.

Reflection of radio waves from moving ships discovered by Dr. A. Hoyt Taylor and L. C. Young of the Naval Aircraft Radio Laboratory, one of the forerunners of the Naval Research Laboratory. This was the first detection of moving objects by radio, later known as radar.

1923 **Rigid airship** "Shenandoah" constructed; the Navy's rigid airship program established the manufacture of duralumin in this country of which all current airplanes are constructed.

Airborne high-frequency transmitter and receiver in rigid airship installed by Naval Research Laboratory in "Shenandoah" for trip across the continent and back.

Naval Research Laboratory, Washington, D. C., placed in commission; recommendation of establishment previously made by Thomas A. Edison.

Pictures of President Warren G. Harding were transmitted by radio facsimile from Washington, D. C., to Philadelphia, Pa

Remote control by radio of a naval ship at sea, "Boggs," demonstrated by Naval Aircraft Radio Laboratory.

1924 **High-power crystal controlled transmitter** installed by Naval Research Laboratory.

Potentialities of high frequencies for naval communications demonstrated by Naval Research Laboratory, based on its original ionospheric investigations.

Regular daylight transcontinental radio communications on high frequencies accomplished.

Remote control of an aircraft by radio demonstrated by Naval Research Laboratory. These experiments presaged guided missiles.

Vacuum tube transmitters replaced original arc transmitters at NAA, Arlington, Va.

1925 **Height of ionosphere** measured by Naval Research Laboratory and the Carnegie Institution of Washington, D. C.

Helium in decompression investigated to reduce the time taken in surfacing.

Mechanical television apparatus, using rotating scanning disc, demonstrated.

Radio transmitting equipment embodying the electronic "pulse" principle, later used in radar, developed by Naval Research Laboratory.

Wireless communications maintained on expedition to the North Pole by Donald B. MacMillan with U. S. Naval communications on high frequencies.

Damaging effect of aqueous corrosion simultaneous with cyclic stress demonstrated by work of D. J. McAdam, Jr., who coined term "corrosion fatigue." 1926

Navy plan for world-wide frequency allocation adopted by International Radio Convention. 1927

World's first gyro system installed to correct automatically for ship's roll and pitch for gunnery purposes.

Aerial exploration expedition to the Antarctic, including a flight over the South Pole, by Cdr. Richard E. Byrd. The Naval Communications Service rendered wireless service between the expedition units and between the Antarctic and the United States. 1928

Magnetostriction devices developed suitable for use in generating and receiving underwater sound. 1929

Naval Ordnance Laboratory established at Navy Yard, Washington, D. C.

Norden automatic bomb sight developed.

Potentialities of very high frequencies (VHF) for naval communications demonstrated by Naval Research Laboratory.

Reflection of radio waves by aircraft in flight discovered by L. A. Hyland; first detection of aircraft by radio. 1930

Variable pressure water tunnel installed at the Model Basin for study of propeller cavitation.

High-power vacuum-tube transmitters used, first installation in the Philippines. 1932

"Momsen Lung" used for escape from sunken submarine "Sailfish."

Automatic train and elevation installed on a 5"/25 gun. This is believed to have been the world's first such installation. 1933

First U. S. stratospheric sealed-cabin balloon flight establishing new world altitude record made by Lt. Cdr. Settle (USN) and Major Fordney (USMC).

All-welded warships introduced. 1934

First aircraft carrier, "Ranger," designed for the purpose, placed in commission.

1934	**First pulse radar** in the world built and tested at Naval Research Laboratory by L. C. Young and R. M. Page.
	High-pressure high-superheat steam for marine propulsion introduced.
	High-speed computer introduced into study of the anti-aircraft problem; Navy sponsored the development of large high-speed digital computers at the Harvard Computer Laboratory for use in the solution of scientific and engineering problems.
	World's first radar apparatus developed at the Naval Research Laboratory.
1935	**Sonar** development for underwater detection of submarines.
1936	**Transmission and reception of wave pulses by one radar antenna** accomplished.
1938	**IFF equipment for identifying friendly naval aircraft** devised and demonstrated by Naval Research Laboratory.
	Radio systems for homing aircraft on carriers (models YE and YG) devised and demonstrated by Naval Research Laboratory and used by Navy throughout World War II and to date.
	Shipboard operational radar installed, "New York."
1939	**Landing Vehicle Tracked** (LVT) development begun by Marines, which later made possible the attack of coral-protected islands of the Pacific during World War II; formation of doctrine for amphibious warfare completed in 1940.
	Potentialities of ultra high frequencies (UHF) for naval communications demonstrated by Naval Research Laboratory.
	Research in atomic energy and nuclear physics begun at Naval Research Laboratory; first thermal diffusion plant for separation of uranium isotopes.
1940	**David W. Taylor Model Basin** opened at Carderock, Md.
	Degaussing and demagnetization methods for ships developed by Naval Ordnance Laboratory to protect ships from magnetic mines.
	Mobile base hospitals begun, with portable buildings and motorized hospitals.
1941	**Acoustic ray diagrams and sonar prediction charts** developed.
	Fire control radars installed in naval vessels. This is believed to have been the first naval application of radar for gunnery.
	First escort carrier, "Long Island," placed in commission.
	Higgins boat with bow ramp introduced.
	Lobe comparison techniques developed for determination of sonar bearing deviation.

Radio-sono buoy devised and demonstrated by Naval Research Laboratory. 1941

Teletypewriter circuit installed linking Washington, Norfolk, Philadelphia, New York, New London, Boston and Portsmouth.

Underwater Sound Laboratory established in New London.

Desalination apparatus developed for use on lifeboats and life rafts. 1942

Gyro lead computing gun-sight installed on 20mm AA guns. This is believed to have been the world's first use of the gyro principle for computing gun-sight lead angles.

Homing weapons developed successfully by Bell Telephone Laboratories and Harvard University; homing torpedo completed trial runs.

Jet-assisted Take-off (JATO) used; this may have been the world's first use of rockets for assisting aircraft in takeoff.

Mechanical time fuses of simple economical construction developed by Naval Ordnance Laboratory for anti-aircraft projectiles.

National Naval Medical Center opened at Bethesda, Md., with Naval Medical School, Naval Hospital, Naval Medical Research Institute, Naval Dental School, Naval School of Hospital Administration.

Operational radar arrived in the fleet in quantity to revolutionize tactics and fire control.

Proximity fuze, "VT," developed by OSRD-Navy, successfully tested; "Helena" was first to use it against the enemy in January 1943.

Radar countermeasures intercept receivers and jammers devised and furnished the fleet by Naval Research Laboratory.

Blood plasma used in field surgery. 1943

First guided missile employed in war against an enemy. It was a small drone carrying a 2000-pound bomb.

Homing torpedo used in combat.

Magnetic airborne detector developed by Naval Ordnance Laboratory

Normal mode analysis of low frequency sound propagation in shallow water.

Orr-Trueta fixation and closed method of treating open wounds and compound fractures applied.

Radio countermeasures for guided missiles devised and installed in naval ships by Naval Research Laboratory.

Sound Fixing and Ranging (SOFAR) developed.

1944 **Acoustic depth charge pistol** developed by Naval Ordnance Laboratory.

Clipper correlator and other types of modern signal processing developed for sonar receivers, active and passive.

Electronic aids for swimmers and amphibious forces developed for communication and navigation using underwater sound.

Facsimile (radiophoto) facilities installed at Naval Communications Stations (Washington, D. C., San Francisco, Pearl Harbor, and Guam).

Forward firing rocket attack from U. S. aircraft made against German U-Boat by carrier-based aircraft from "Block Island."

Frequency modulation sonar applied to mine detection.

New landing ships, "Dock Landing Ship (LSD)," "Medium Landing Ship (LSM)," and "Tank Landing Craft (LCT)" introduced.

Pressure mine developed by Naval Ordnance Laboratory.

Radio circuit using Single Side-Band technique became operational between Pearl Harbor, T. H., and Washington, D. C.

Scanning Sonar developed with omnidirectional outgoing pulse and rotating receiving beam.

Shipboard radioteletypewriter equipment successfully tested.

Underwater telephone developed for voice communication using single side-band suppressed carrier, Underwater Sound Laboratory.

1945 **Automatic tracking blindfiring radar directors** installed for anti-aircraft defense. This is believed to have been the first such installation in the world.

Beach mine locator developed for Underwater Demolition Team by the Naval Ordnance Laboratory.

Color facsimile picture transmitted and received over radio circuit.

Convergence zone phenomena discovered in the deep ocean.

"Dunked" sonar developed for use from helicopters.

Guided missile "Bat," only aerial homing missile to be used in World War II, launched from naval aircraft against enemy shipping in Balikpapen Harbor, Borneo.

Modern rocket ships, probably world's first, used in combat at Okinawa.

Facsimile (radiophoto) photographs of Japanese surrender transmitted from "Missouri" to the United States.

Ramjet acceleration in supersonic flight demonstrated experimentally by Bureau of Ordnance "Bumblebee" program.

Ramjet aircraft first in flight.

Jet aircraft made successful landings and take-offs from carrier "Franklin D. Roosevelt."	1946
Michelson Laboratory opened at Naval Ordnance Test Station, Inyokern.	
Naval Ordnance Laboratory Magnetic Materials Facility established which produced "Orthonol" (1948), "Bismanol" (1952), "Alfenol" (1953), and "Thermenol" (1954).	
New Naval Ordnance Laboratory cornerstone laid at White Oak, Md.	
Office of Naval Research established by Congress.	
World's record distance flight of over 11,000 miles nonstop and nonrefueled from Perth, Australia, to Columbus, Ohio, made by a P2V Neptune patrol bomber; this record of the "Truculent Turtle" still stands after 12 years.	
Development and first successful flights of new plastic balloons starting much scientific research in the upper atmosphere. The nature of primary cosmic radiation was discovered on these flights. Laboratory study of high energy nuclear particles was spurred.	1947
Guided missile, "Loon," first launched from a submarine.	
Official world airspeed record of 650.796 mph. set by Douglas D558 Skystreak.	
Ship-to-shore facsimile communication accomplished between an Ice-Breaker ship in the Antarctic and Washington, D. C., 10,581 miles, world record.	
U. S. Naval Radiological Defense Laboratory established as a result of Operation "Crossroads."	
Cholera treatment on basis of fluid and electrolyte balance.	1948
Guided missiles experimental and test ship, "Norton Sound," first operated.	
Passive sonars developed for submarines practical for 50 to 100 mile range, Underwater Sound Laboratory.	
Telemetering of physiological data, air to ground.	
"Terrier" guided missile prototype successfully fired.	
Viking rocket successful; first high altitude American rocket.	
Antiferromagnetism detection by neutron diffraction at the Naval Ordnance Laboratory in conjunction with the Oak Ridge National Laboratory.	1949
Bone and Tissue Bank established, National Naval Medical Center.	
Gasless delay mixtures for use in ordnance developed by the Naval Ordnance Laboratory.	

1949 **"Lark" guided missile** launched from shipboard, "Norton Sound."

Measurement of earth's magnetic field to altitude of 105 km by Naval Ordnance Laboratory in conjunction with the Applied Physics Laboratory of the Johns Hopkins University.

Naval Ordnance Laboratory Aeroballistics Research Facility established.

Real gas effects on flows around blunt shaped bodies at hypersonic speeds first demonstrated experimentally at the Naval Ordnance Laboratory.

Textbook on atomic medicine written by RAdm. C. F. Behrens.

1950 **"Albacore" hull form** developed by the Bureau of Ships and the David Taylor Model Basin.

Anti-tank aircraft rockets (ATAR) developed, tested and fired in combat, all in period of less than 90 days.

Lightweight titanium alloy developed for use in jet aircraft engines by Bureau of Aeronautics; as strong as high strength steel and only half as heavy.

Submarine radio rescue buoy devised.

Tissue Bank established at National Naval Medical Center.

Anti-fragmentation garment (armored vest) in successful field trial with Marine Corps in Korea.

1951 **Distortion of crystal structure lattice constant** at paramagnetic-antiferromagnetic Curie temperature discovered at the Naval Ordnance Laboratory.

First U. S. hypersonic wind tunnel operated at Mach 10 without air liquefaction at the Naval Ordnance Laboratory.

First U. S. pressurized ballistics firing range operated at the Naval Ordnance Laboratory.

Moon reflection capabilities for communications demonstrated by Naval Research Laboratory.

Non-destructive inspection of propellant grains by X-ray fluoroscopy developed by the Naval Ordnance Laboratory.

Smoke trail technique and determination of blast from nuclear bombs developed by the Naval Ordnance Laboratory.

Speed record of 1238 mph. and altitude of 79,494 feet attained by Navy Douglas D558-2 Skyrocket in experimental test flights.

Theoretical calculations of heat transfer to body shapes suitable for ballistic missiles conducted at the Naval Ordnance Laboratory.

1952 **Minesweeping by helicopter** accomplished at the Navy Mine Defense Laboratory, Panama City, Fla.

Rockets from high altitude balloons first fired; threefold height increases resulted.

Theory of noise in semi-conductors developed by the Naval Ordnance Laboratory.

Two U. S. Navy "Terrier" guided missiles destroyed two drone airplanes. These were the world's first cases of destruction of airplanes by surface-to-air guided missiles.

World's largest human centrifuge commissioned at Naval Air Development Center, Johnsville, Pa.

Angled flight deck operational tests begun on "Antietam." **1953**

Chemical finish for fiber glass developed at Naval Ordnance Laboratory; significantly increased strength and stiffness in both wet and dry applications.

Delta-wing jet seaplane made first flight at San Diego.

Farnsworth Lantern adopted as test for color vision.

First carrier-based airplane to hold the official world air-speed record at 752.9 mph., Navy Douglas XF4D-1 Skyray. It also set the 100-kilometer closed course record at 728.11 mph.

First manned aircraft to attain a speed of twice the speed of sound, 1327 mph., Navy Douglas D558-2 Skyrocket. It flew higher (83,235 ft.) than man had ever flown.

Nuclear propulsion prototype plant at Arco, Idaho, first operated on nuclear power.

Sidewinder, air-to-air missile, utilizing heat-seeking or infrared device, test-fired at the Naval Ordnance Test Station, China Lake, Calif.

World's first VTOL airplane, "Pogo," made successful transition from hover to level flight and return to hover.

High sensitivity antisubmarine aircraft-laid bottom mine developed by the Naval Ordnance Laboratory. **1954**

Manned experimental ships successfully maneuvered in fallout from thermonuclear weapons.

Nuclear depth bomb developed by Naval Ordnance Laboratory.

Nuclear submarine, "Nautilus," world's first atomic-powered vessel commissioned.

Passive method of underwater fire control, PUFFS, developed by the Naval Ordnance Laboratory.

Radio-active fallout effects studied in the Marshall Islands.

Voice communication over moon reflection circuit accomplished by Naval Research Laboratory.

World's most powerful VLF radio transmitter (1.2 Mega-watts), Jim Creek Valley station in state of Washington, commissioned.

Freezing whole blood developed as laboratory process for purpose of preservation for clinical use. **1955**

1955 **Guided missile cruiser,** "Boston," placed in commission.

Miss distance indicator developed by the Naval Ordnance Laboratory for determining accuracy of anti-aircraft projectiles or missiles.

Nuclear depth bomb entered stockpile; developed by the Bureau of Ordnance and the AEC.

Record of 695.163 mph. for 500-kilometer closed course set by Navy Douglas A4D-1 Skyhawk.

Teletype transcontinental circuit using moon as a relay established by Naval Research Laboratory.

U. S. Navy's "Terrier" surface-to-air guided missile, worlds' first guided missile to become operational in a fleet; installed aboard "Boston."

1956 **Air-sea-rescue color scheme** designed.

Drugs for prevention and treatment of motion sickness evaluated in sea trials.

Experimental navigational ship, "Compass Island," commissioned to help in scientific development and evaluation of navigation system independent of shore-based aids.

Heat-stress casualties studied with successful revision of training schedules of Marine Corps recruits.

Human Gradient Calorimeter operated at Naval Medical Research Institute, representing first great advance in this type of instrument for over 50 years.

Operationally equipped jet plane, F8U-1 "Crusader," awarded Thompson Trophy, first military airplane to fly faster than 1000 mph.

Rocket-powered helicopter in first successful flight.

Rocket-propelled nuclear weapon entered stockpile.

Solid propellant grains produced of a size applicable to a ballistic missile (Polaris).

Stratolab balloon rose to 76,000 feet in flight designed to gather scientific data at high altitudes; record altitude for manned balloon.

Transoceanic teletype circuit using moon as reflector established by .Naval Research Laboratory between Washington, D. C., and Hawaii.

1957 **Arctic ice pack trip** of 1000 miles completed by "Nautilus."

Automatic carrier landing system given first successful test on "Antietam."

Clinical Investigation Center established at U. S. Naval Hospital, Oakland, Calif.

Development of hydrofoils, major improvement in high speed boats. 1957

"Minitrack" radio tracking system employed to track earth-circling satellites.

Plastic balloons became operational instruments for Naval Weather Service with regular unmanned flights across Pacific from Japan to collect wind information at 30,000 feet.

"Solion," a low frequency amplifier operating upon an electrochemical process developed by the Naval Ordnance Laboratory.

Start of astronomical studies from edge of space; first telescope carried on plastic balloon above 95 percent of earth's atmosphere for study of motions in solar atmosphere. Balloon-borne study of Mars begun.

Supersonic transcontinental nonstop flight by F8U-1 "Crusader," "Operation Bullet."

Text and reference work on underwater sound, "Fundamentals of Sonar" by J. W. Horton, published by U. S. Naval Institute.

Theory of Vibrational-Translational Relaxation in Liquids by the Naval Ordnance Laboratory.

Aircraft-laid moored mine developed by the Naval Ordnance Laboratory. 1958

Continuous submersion for 60 days by "Seawolf" without replenishment of air.

First primate in space; a squirrel monkey was fired 280 miles into space in an Army Jupiter vehicle. Animal prepared at National Medical Research Institute and SAM, Pensacola, and telemetering record of data by Navy.

First undersea voyage across the top of the world from Pacific to Atlantic Ocean, a distance of 1830 miles, made by "Nautilus."

"Full Pressure" suit enabled flight surgeon, Dr. Tabor, to live longer at a higher simulated altitude than any other person in history.

Installation of Nuclear Reactor at National Naval Medical Center for preparation of short life radioisotopes.

Lay down bomb developed by the Naval Ordnance Laboratory.

Radio telescope installed for detection of weak signals from the galaxy (and satellites).

Sea level conditions in sealed cabin at high altitude first employed by stratolab manned balloon; transmitted first television pictures from troposphere.

Ship-to-shore message using meteor burst communication technique received at the Naval Electronics Laboratory, San Diego, Calif., from "Tulare" over a distance of approximately 600 miles.

1958 **Six-hundred-knot flight gear for weapons** developed by the Naval Ordnance Laboratory.

Solid fuel fleet ballistic missile "Polaris" test fired.

Stellar scintillation observations from stratolab balloon made by A. H. Mikesell, Naval Observatory astronomer.

Submarine to launch guided missiles, "Grayback," commissioned and conducted first test firing.

Supercavitating propeller developed, allowing efficient propulsion at much higher speeds.

Transfusion of human red blood corpuscles preserved for 18 months, U. S. Naval Hospital, Chelsea, Mass.

Vanguard test satellite placed in orbit.

Vulnerability of magnetic materials to neutron irradiation evaluated by the Naval Ordnance Laboratory.

Appendix E

References and Source Material

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